1974

The geology of the Upper Cenozoic sediments in the East Rudolf embayment of the Lake Rudolf basin, Kenya

Bruce Eugene Bowen
Iowa State University

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BOWEN, Bruce Eugene, 1943-
THE GEOLOGY OF THE UPPER CENOZOIC SEDIMENTS IN THE EAST RUDOLF EMBAYMENT OF THE LAKE RUDOLF BASIN, KENYA.

Iowa State University, Ph.D., 1974
Geology

University Microfilms, A XEROX Company, Ann Arbor, Michigan

The geology of the Upper Cenozoic sediments in the East Rudolf embayment of the Lake Rudolf basin, Kenya

by

Bruce Eugene Bowen

A Dissertation Submitted to the

Graduate Faculty in Partial Fulfillment of

The Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Department: Earth Science
Major: Geology

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1974

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INTRODUCTION

The Upper Cenozoic deposits in the Lake Rudolf region have received considerable attention in recent years as a result of several discoveries important to the paleontology, anthropology and archeology of East Africa (Arambourg, 1935; Patterson, 1966; Patterson et al., 1970; Howell, 1968; Leakey et al., 1970; Leakey, 1971; 1972; Isaac et al., 1971; Maglio, 1972; Robbins, 1972 and Coppens, 1972; 1973). Of particular interest have been the sediments in the Lake Rudolf basin along the northeastern shore of the lake. More than ninety hominid cranial and post-cranial specimens have been discovered here along with stone artifacts (Leakey et al., 1970; Leakey, 1971; 1972; and Isaac, et al., 1971) and abundant well-preserved artiodactyl, proboscidean and other mammalian remains (Maglio, 1972).

Objectives of this report are (1) to provide for documentation and relative age dating of hominids and other fossils; (2) to establish a sequence of mappable rock units and to determine their distribution; (Figs. 1, 2 and 3); and (3) to describe the units in detail and to determine the environments of deposition represented by them.

Method of Study

Fundamental rock units were established and "marker beds" were delineated. Both were mapped at a scale of 1:24000 on aerial photographs. Over sixty critically located sections were described and sampled in order to determine the lithology, major stratigraphic relationships and depositional history of the strata exposed.

Fig. 1. Geologic map of the Ileret Area, East Rudolf, Kenya

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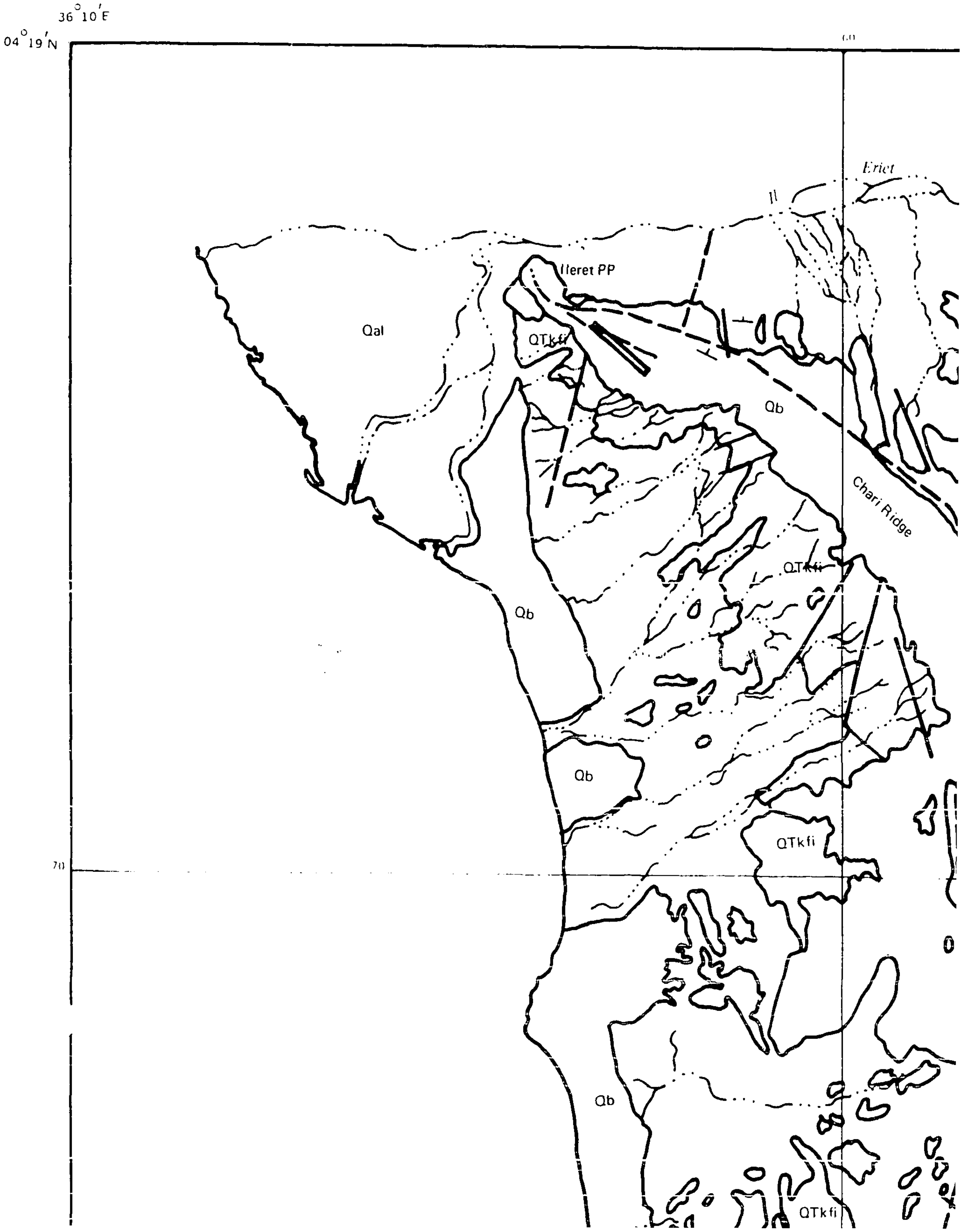
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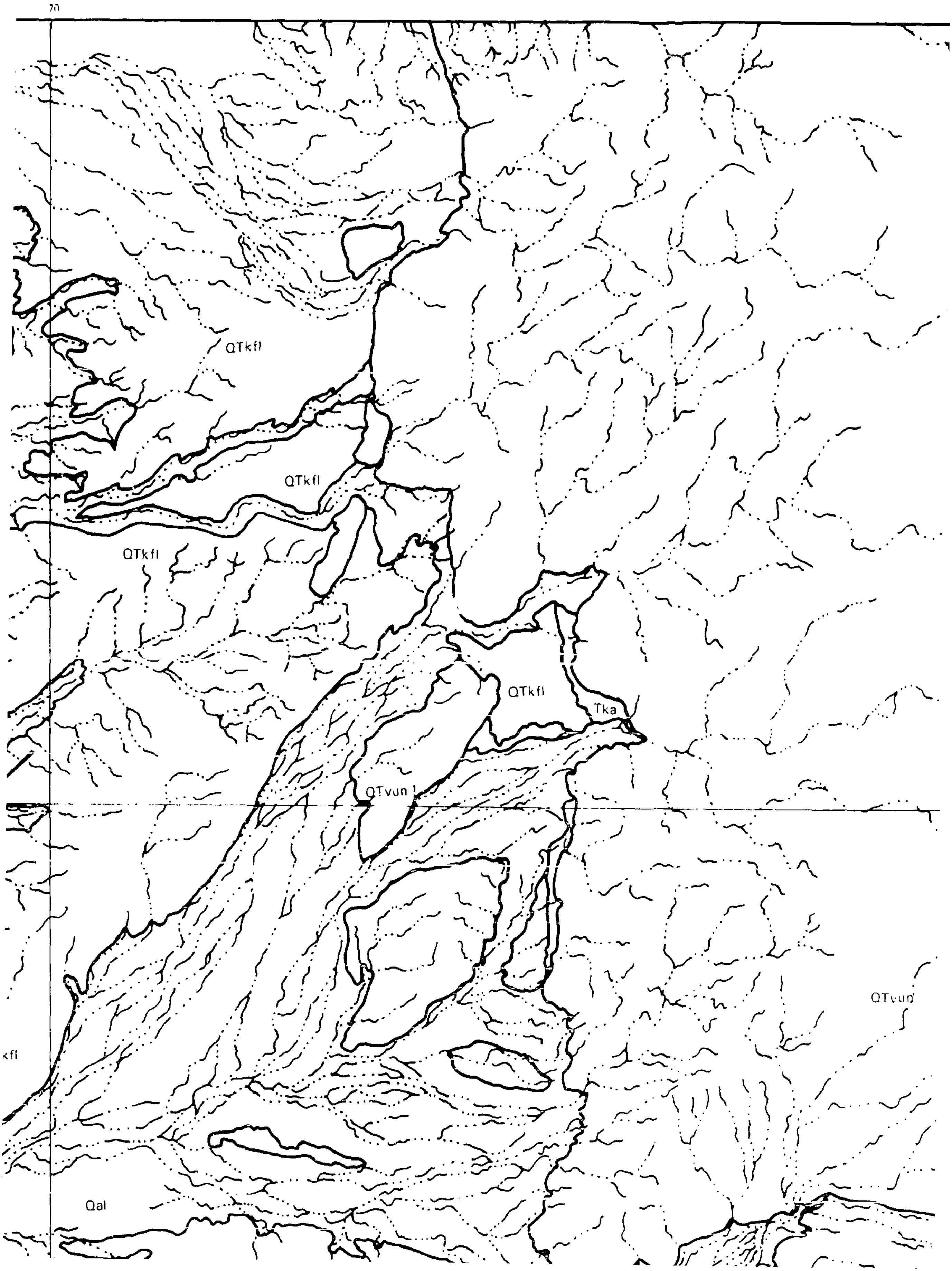
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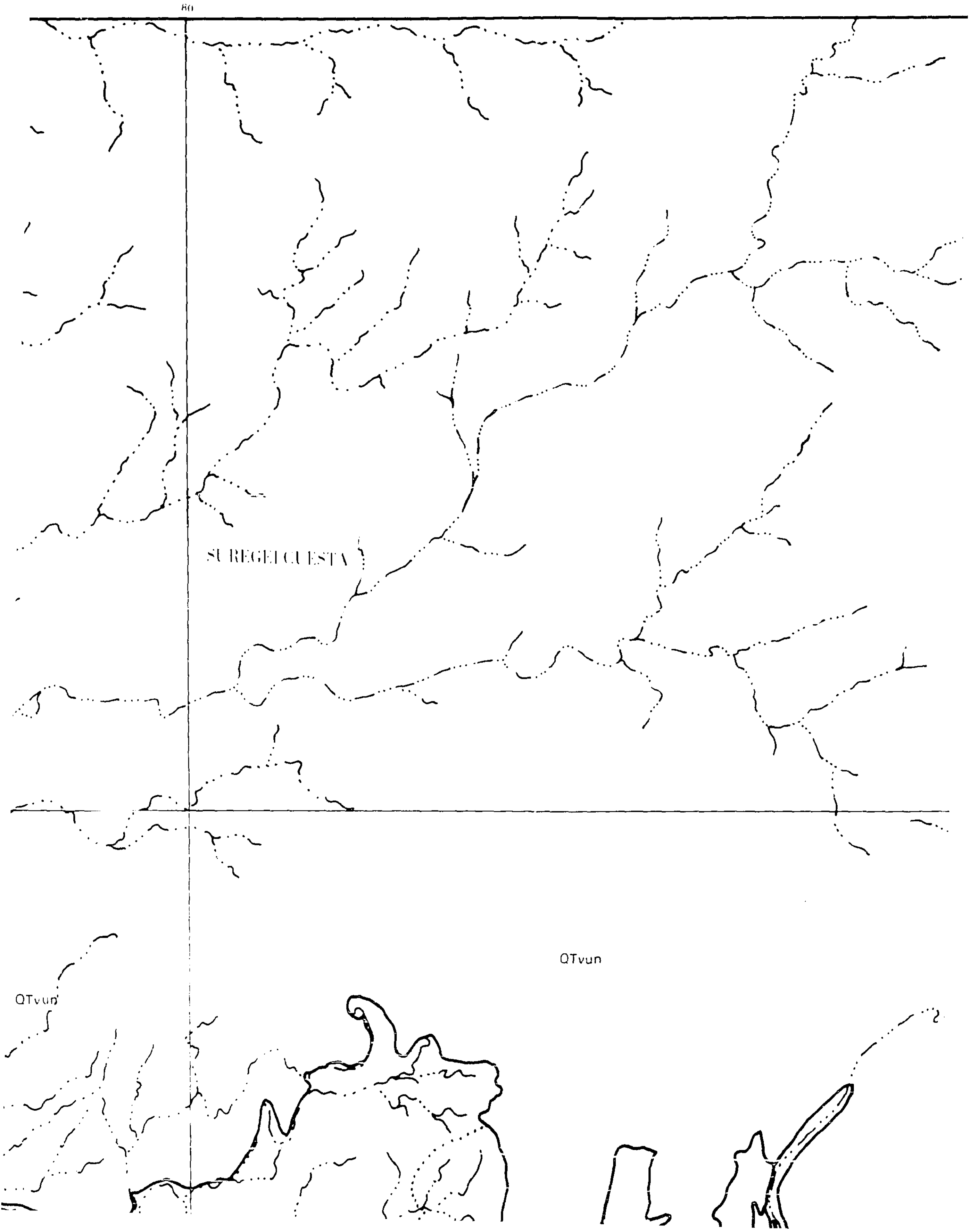
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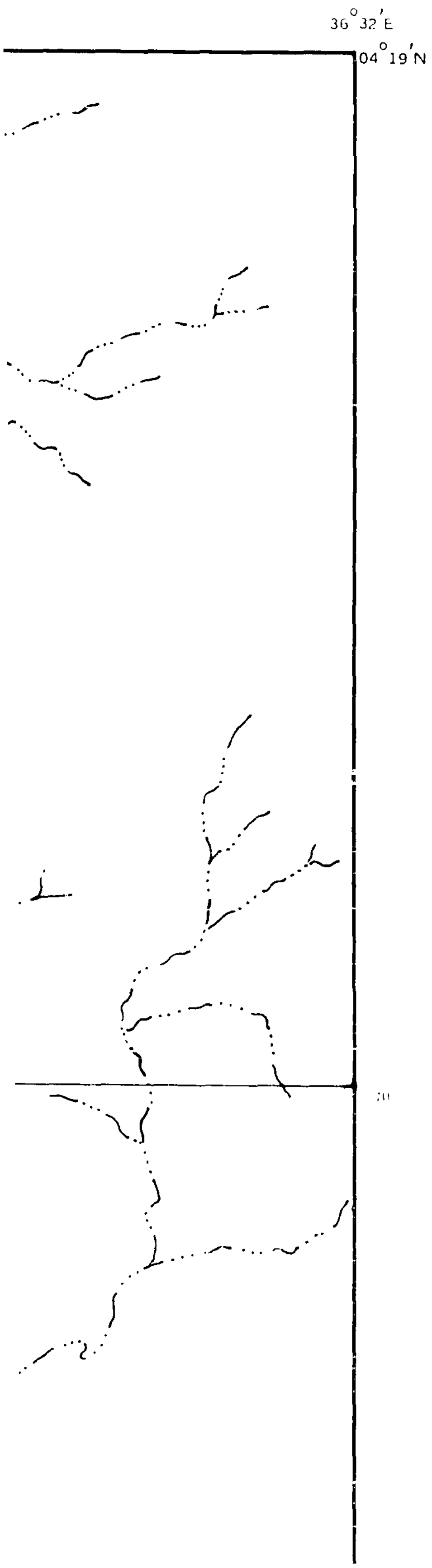

EXPLANATION

Recent

Qal

Alluvium

Unconsolidated deposits of silt, sand, gravel, and cobbles along streams. Includes alluvial fans and terraces.

Qgb

Galana Boi beds

Exhibits high lateral variability; characterized by gray diatomaceous siltstones to claystones with intercalated paleosols, fluvial sandstones and algal stromatolites. Thickness, 0 to 35 meters.

Pleistocene

Guomde Formation

Interbedded thin fossiliferous limestones, tuffs and olive gray mudstones preceded and followed by coarse to fine-grained sandstones interbedded with paleosols. Thickness, 30 to 40 meters.

Koobi Fora Formation

Koobi Fora Formation consists of a series of laminated claystones, siltstones and fine-grained sandstones that are overlain by lenticular conglomerates, mudstones, thin beds of algal stromatolites, fossiliferous limestones and tuffs. Thickness, 180 to 200 meters.

Un

EXPLANATION

Qal

Alluvium

ıted deposits of silt, sand, gravel, ɔbbles along streams. Includes alluvial nd terraces.

Qb

Beach Sand

Unconsolidated deposits of fine sand in beach ridges along the present shoreline.

Qgb

Galana Boi beds

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Guomde Formation

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QUATERNARY

Koobi Fora Formation

'a Formation consists of a series of laminated stones, siltstones and fine-grained sandstones are overlain by lenticular conglomerates, stones, thin beds of algal stromatolites, liferous limestones and tuffs. Thickness, to 200 meters.

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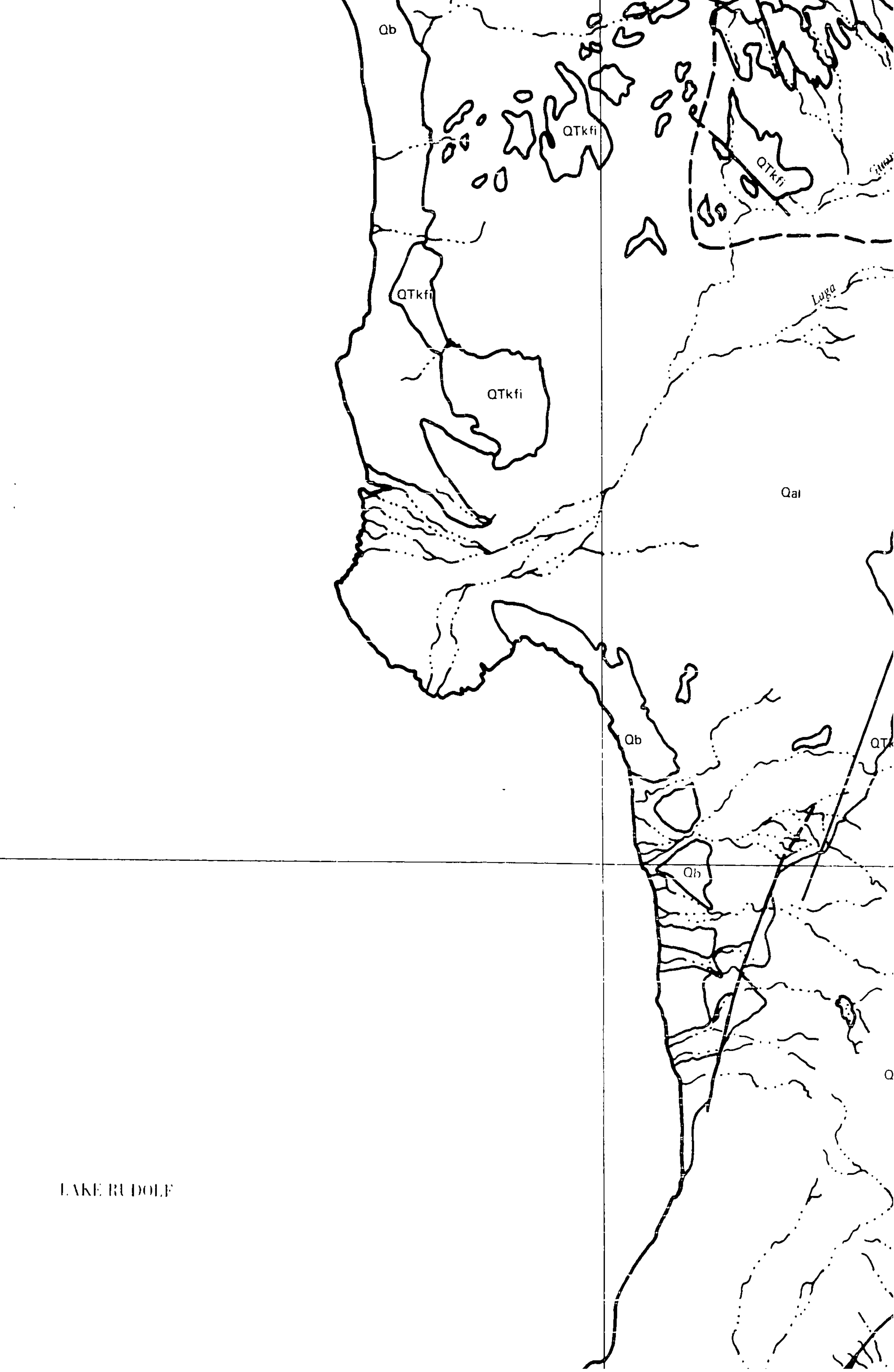
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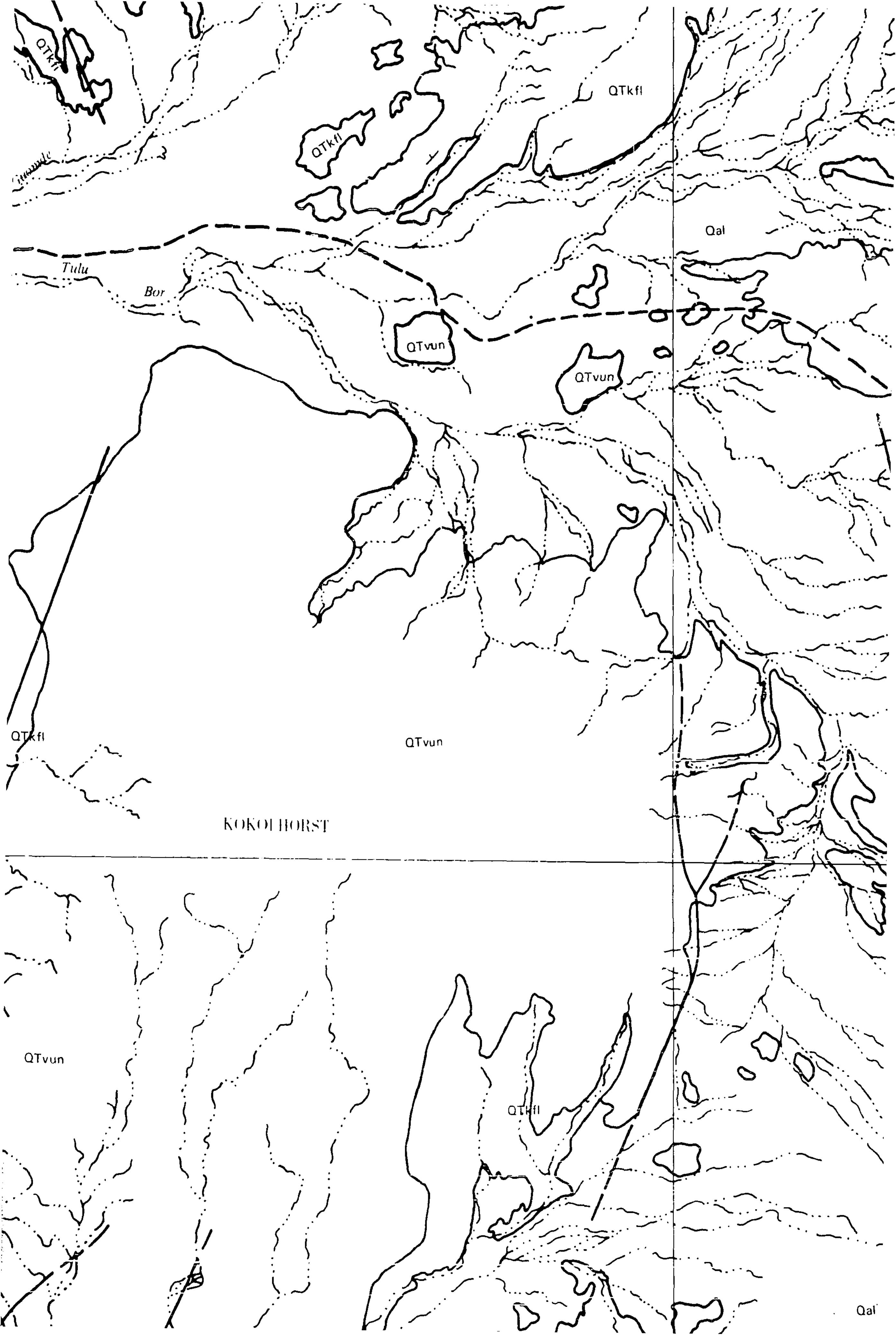

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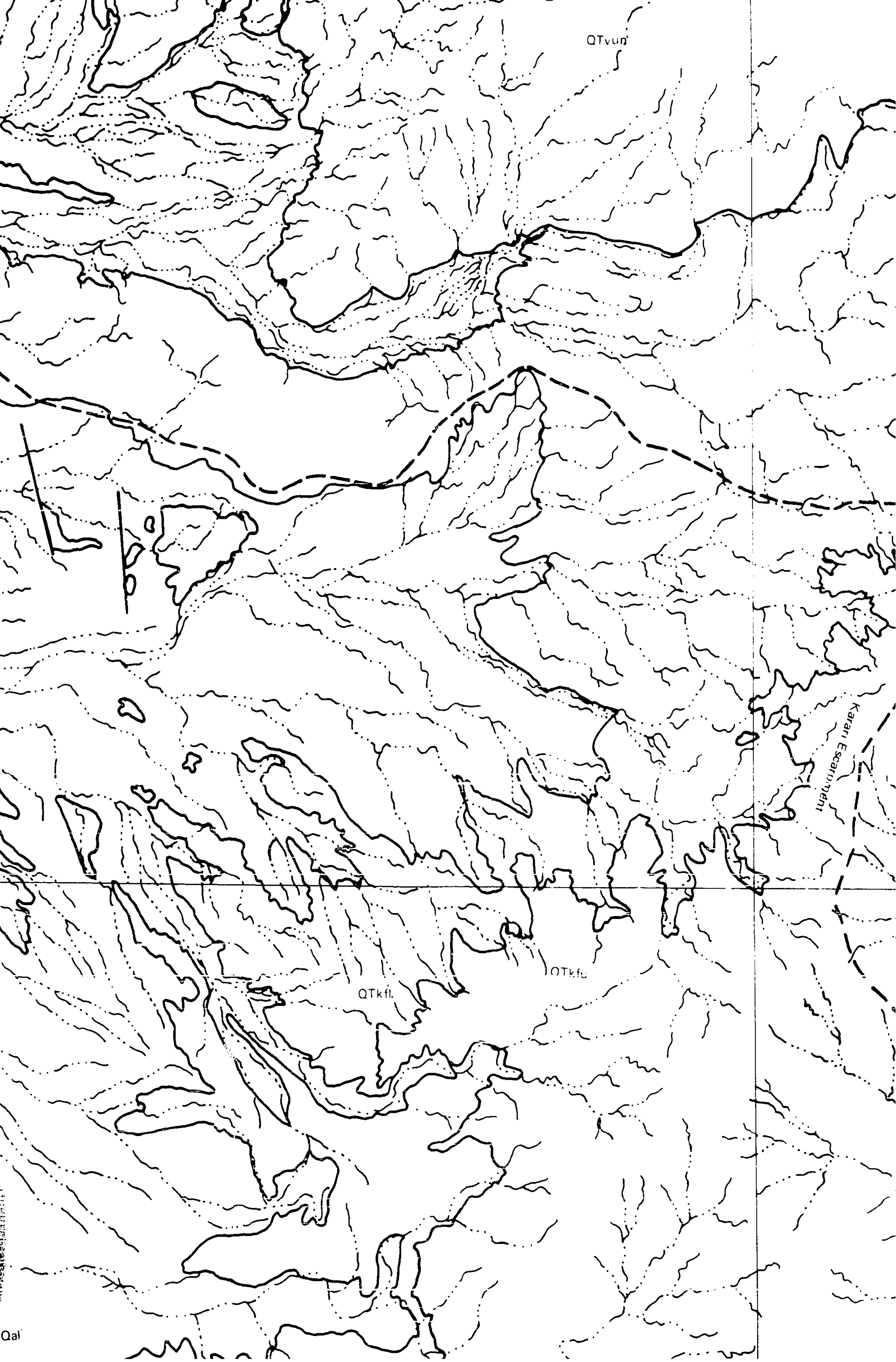

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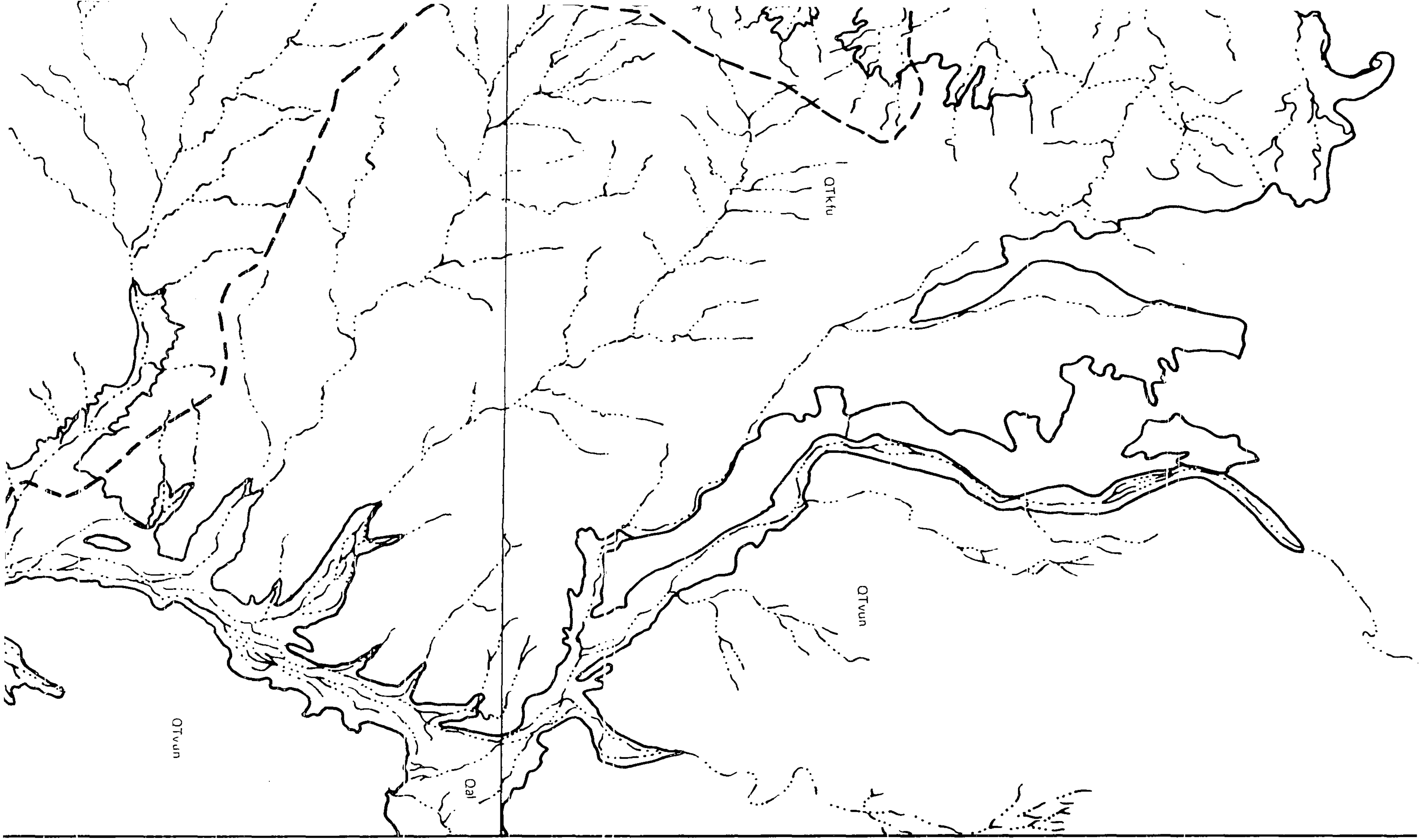

Miocene Pleistocene Undifferentiated *Pliocene* *Plio-Pleistocene*

Plio-Pleistocene

Koobi Fora Formation

Koobi Fora Formation consists of a series of laminated claystones, siltstones and fine-grained sandstones that are overlain by lenticular conglomerates, mudstones, thin beds of algal stromatolites, fossiliferous limestones and tuffs. Thickness, 180 to 200 meters.

QTkfu

Upper member, fluvial deposits of polymictic conglomerates, subarkoses and mudstones that grade laterally into fine-grained sandstones, siltstones, thin beds of algal stromatolites, fossiliferous limestones and tuffs. Thickness, 35 to 80 meters.

QTkfi

Ileret member, basal part consists of fine-grained molluscan limestones that grade upward int conglomeratic sandstones, siltstones, clayst and tuffs. Thickness, 45 tc 65 meters.

QTkfl

Lower member, limonitic, gypsiferous laminated siltstones, claystones, fossiliferous limestones, fine-grained sandstones intercalated with polymictic conglomerates and laminated tuffs. Thickness, 80 to 120 meters.

Pliocene

Tka

Kubi Algi Formation

Oligomictic conglomerates at base grade upward to fine-grained sandstones, cross-bedded tuffs, thin fossiliferous limestones and laminated limonitic siltstones. Sequence is capped by thinly laminated Suregei Tuff Complex. Thickness, 80 to 100 meters.

Miocene Pleistocene Undifferentiated

QTvun

Volcanics, undivided

Lava flows, ignimbrites, tuffs and intrusives of basaltic to rhyolitic composition intercalated with sediments and paleosols of Miocene and Pliocene age.

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QTkfl

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TERTIARY

Tka

Kubi Algi Formation

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QTvun

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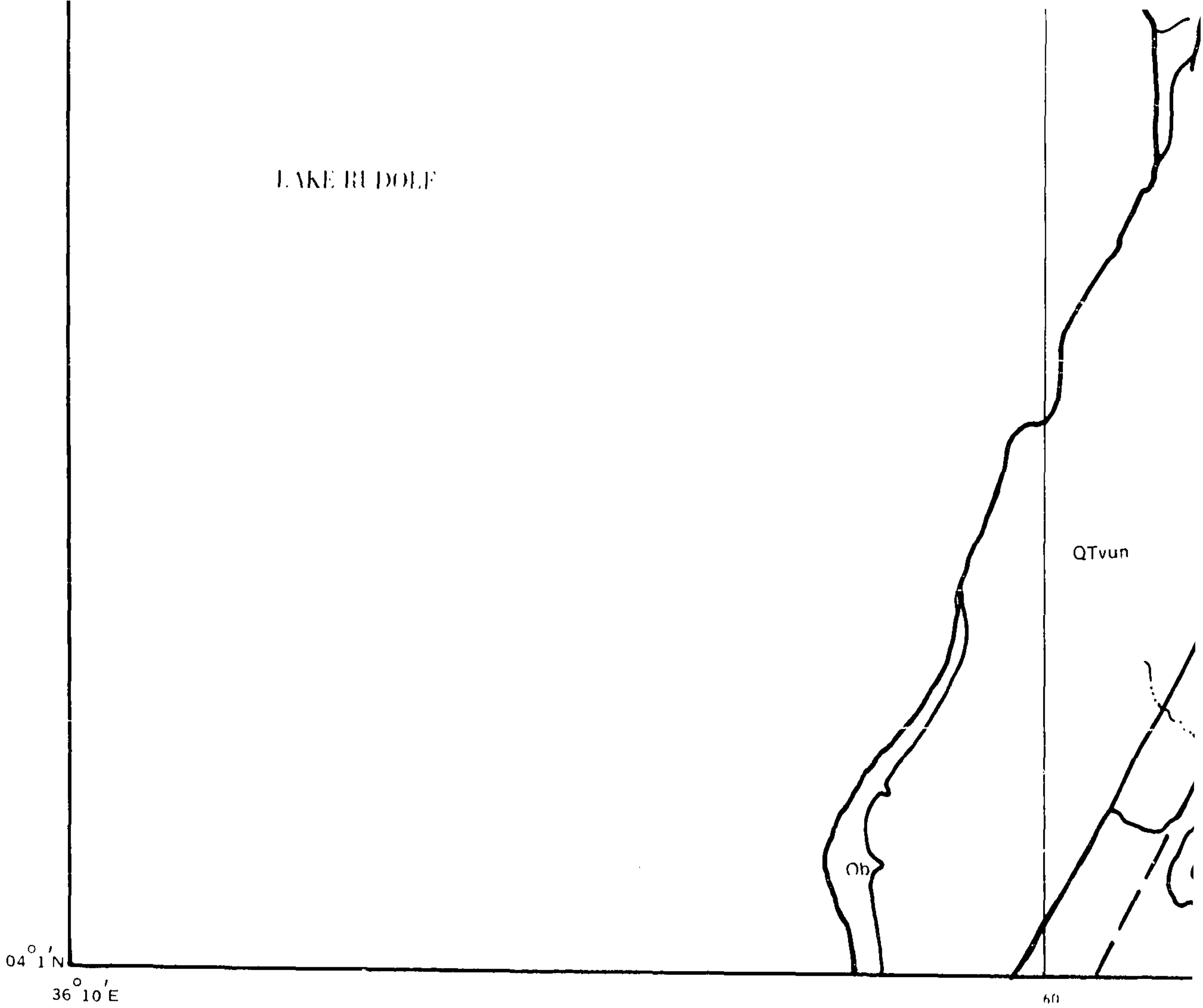
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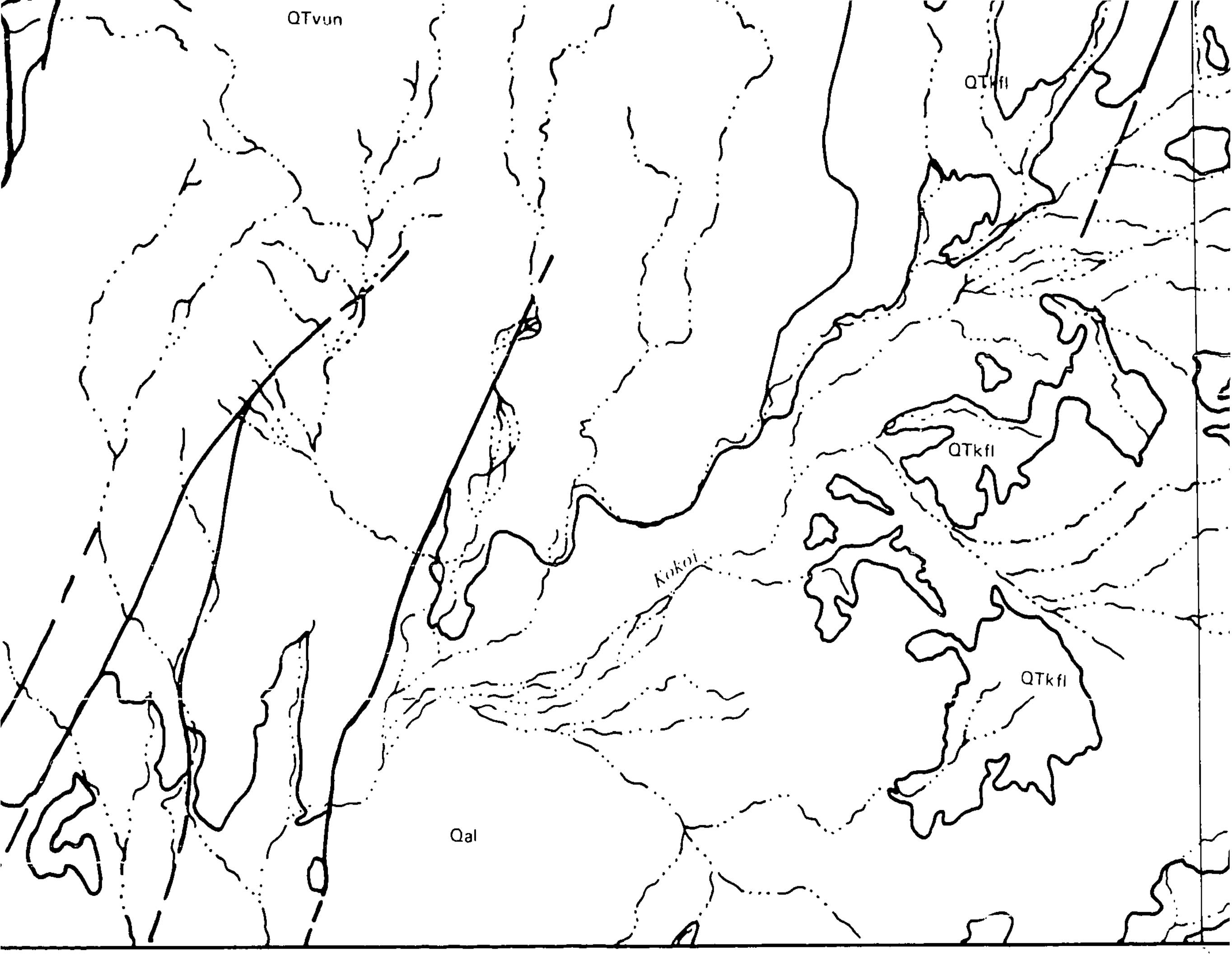

APPROXIMATE MEAN
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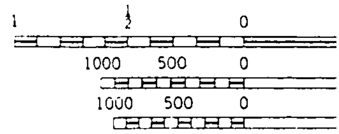

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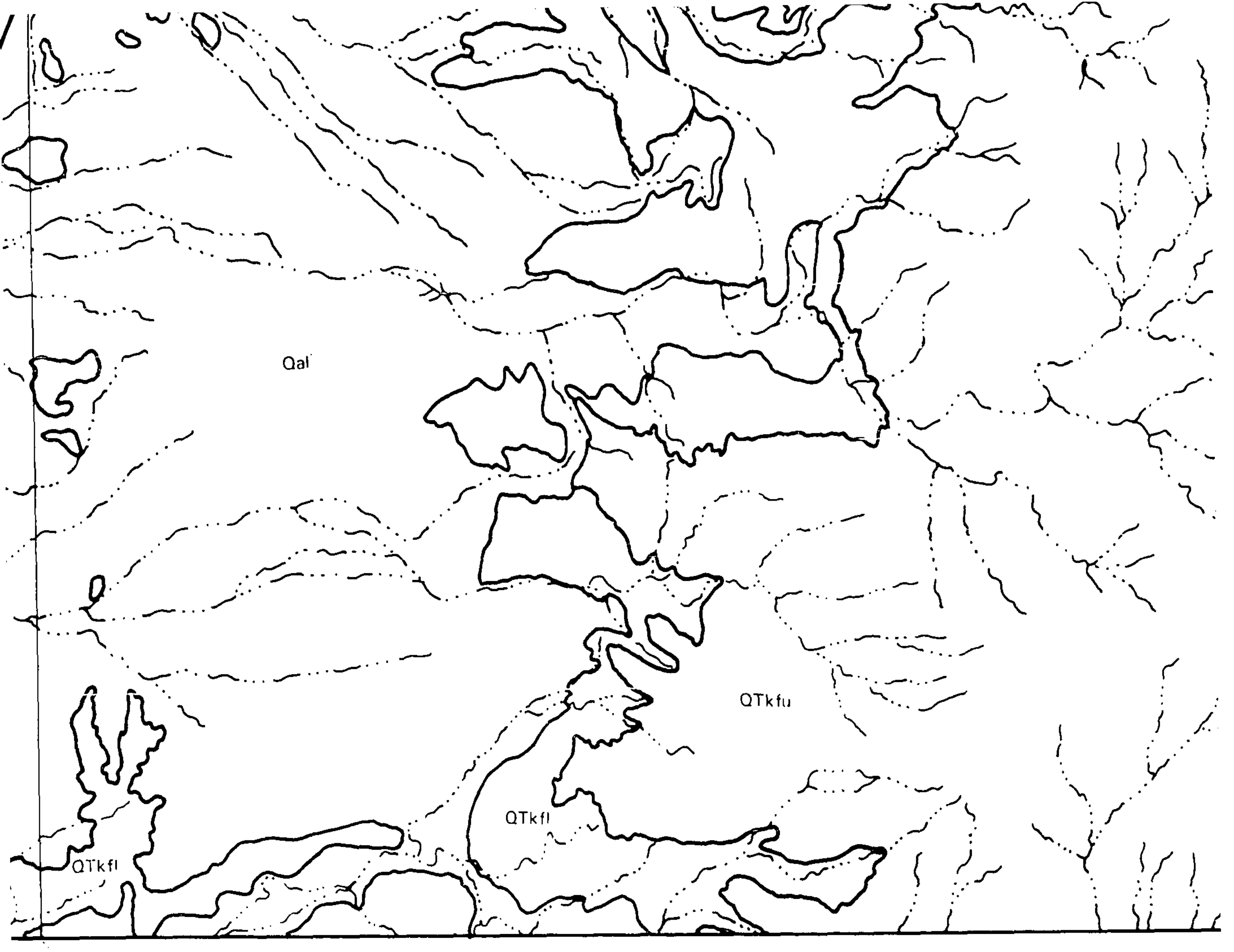

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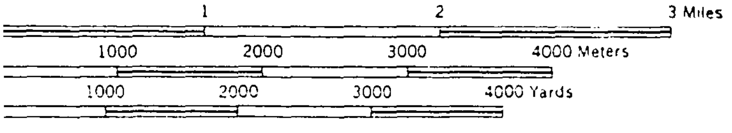

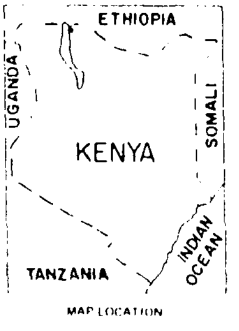

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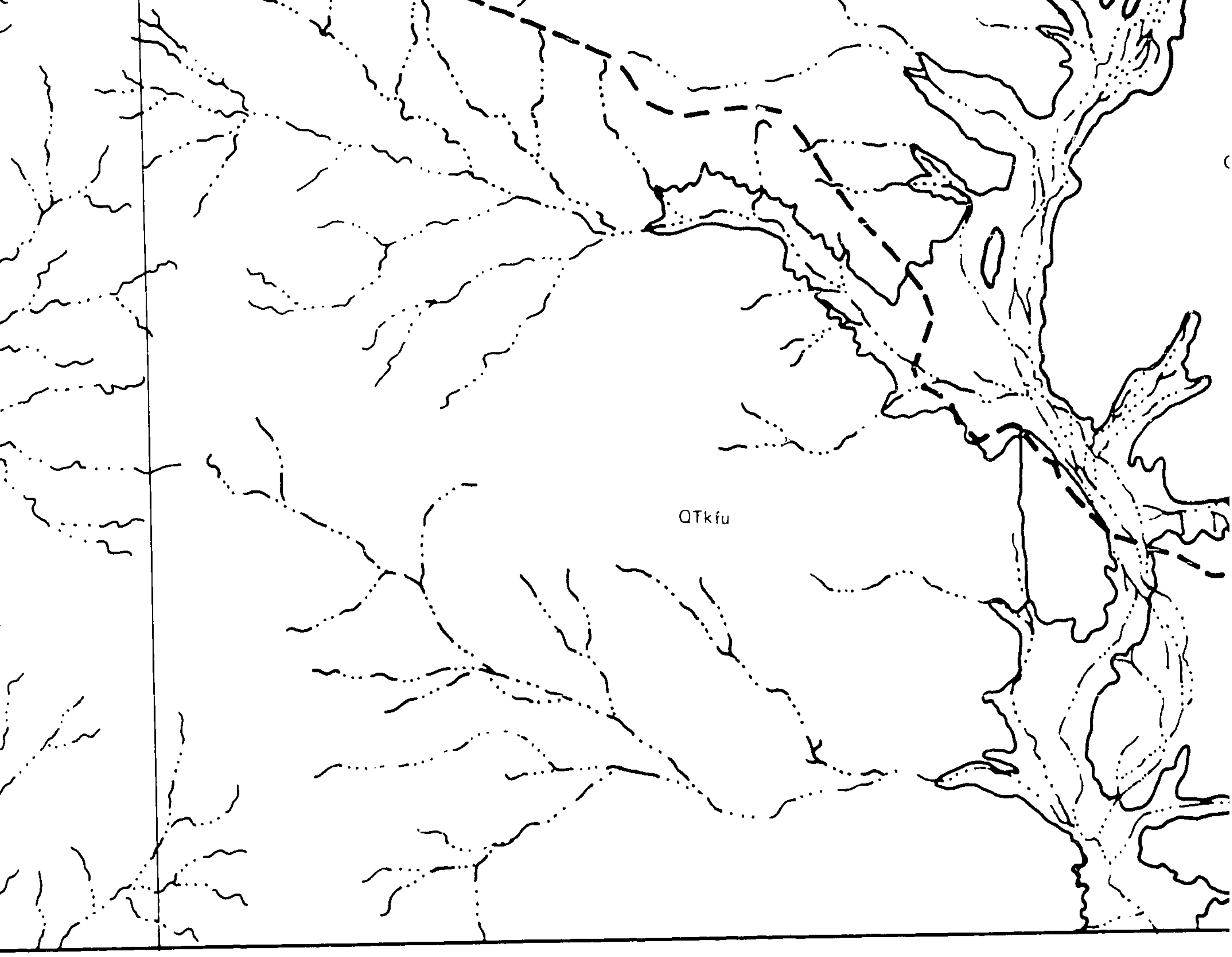

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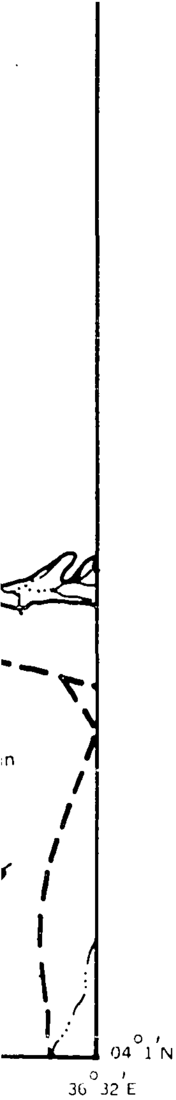

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ed by C. F.
T. F. Cerling

Miocene Pleistocene Undifferen

Volcanics, undivided

Lava flows, ignimbrites, tuffs and intrusives of basaltic to rhyolitic composition intercalated with sediments and paleosols of Miocene and Pliocene age.

U
D

Contact

Normal Fault

Axis of anticline

Axis of syncline

Strike and dip of beds

Volcanics, undivided

flows, ignimbrites, tuffs and intrusives of basaltic to rhyolitic composition intercalated with sediments and paleosols of Miocene and Pliocene age.

Contact

U
D

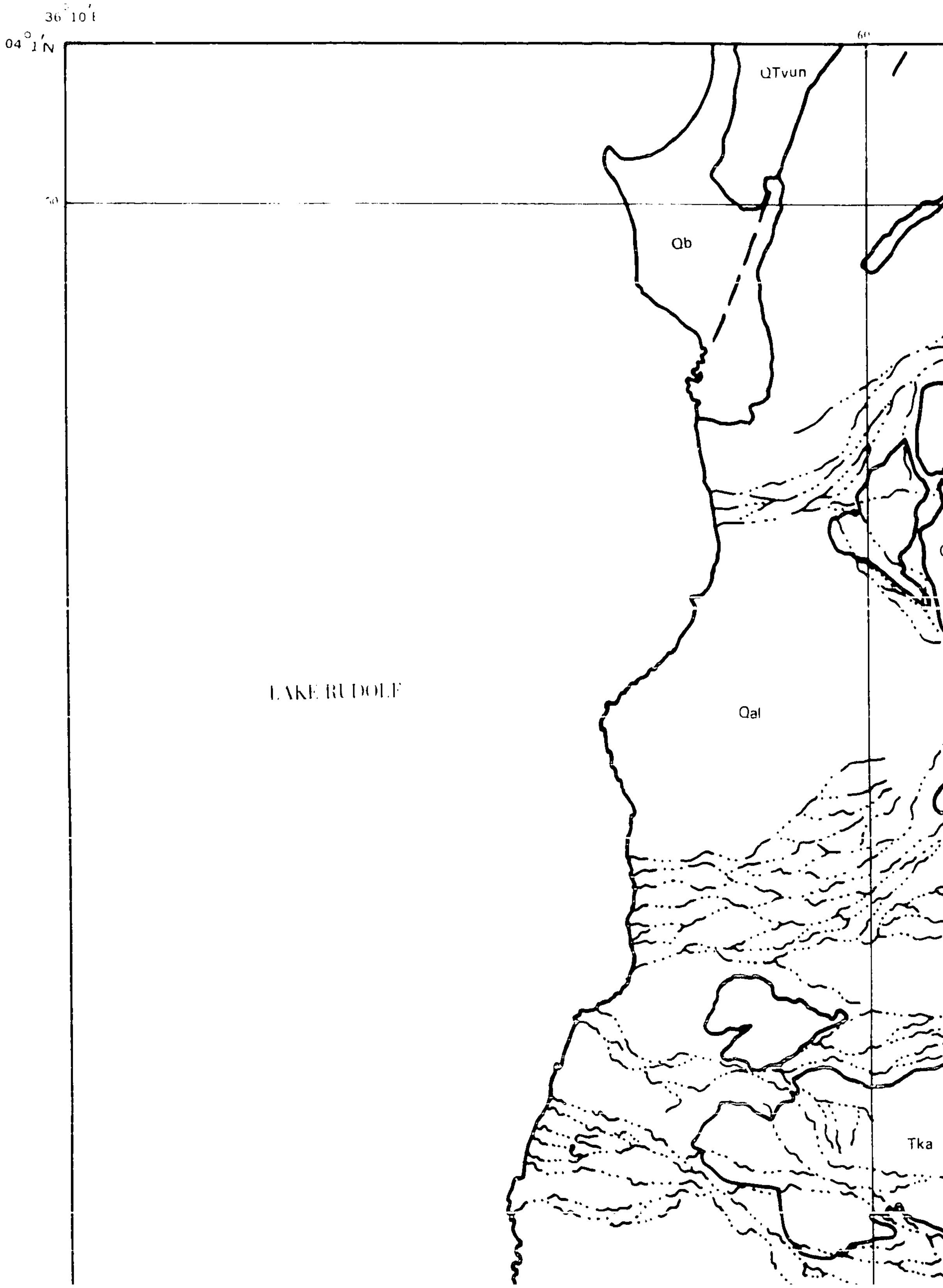
Normal Fault

Axis of anticline

Axis of syncline

Strike and dip of beds

Fig. 2. Geologic map of the Koobi Fora Area, East Rudolf, Kenya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LAKE RUDOLF
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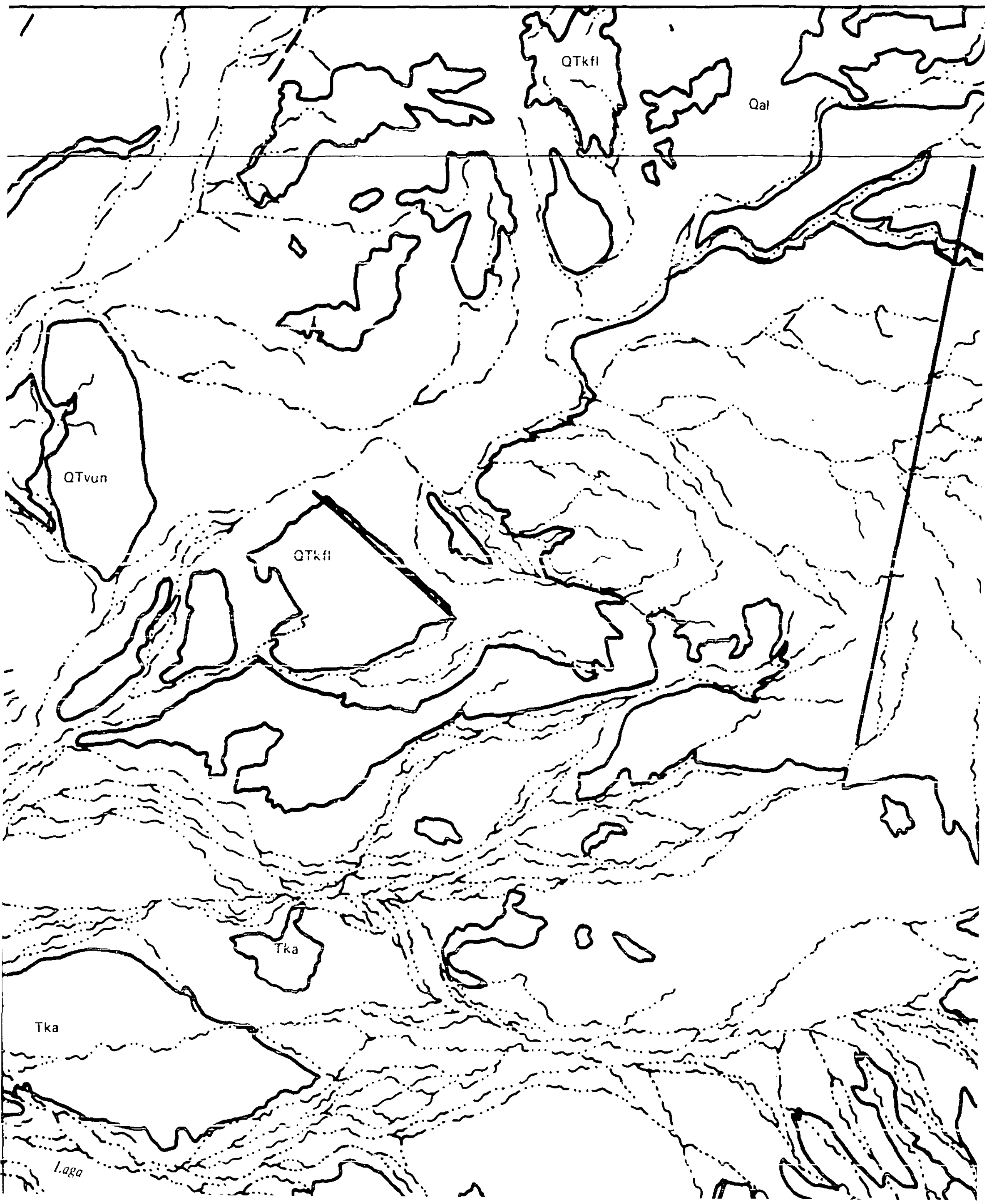

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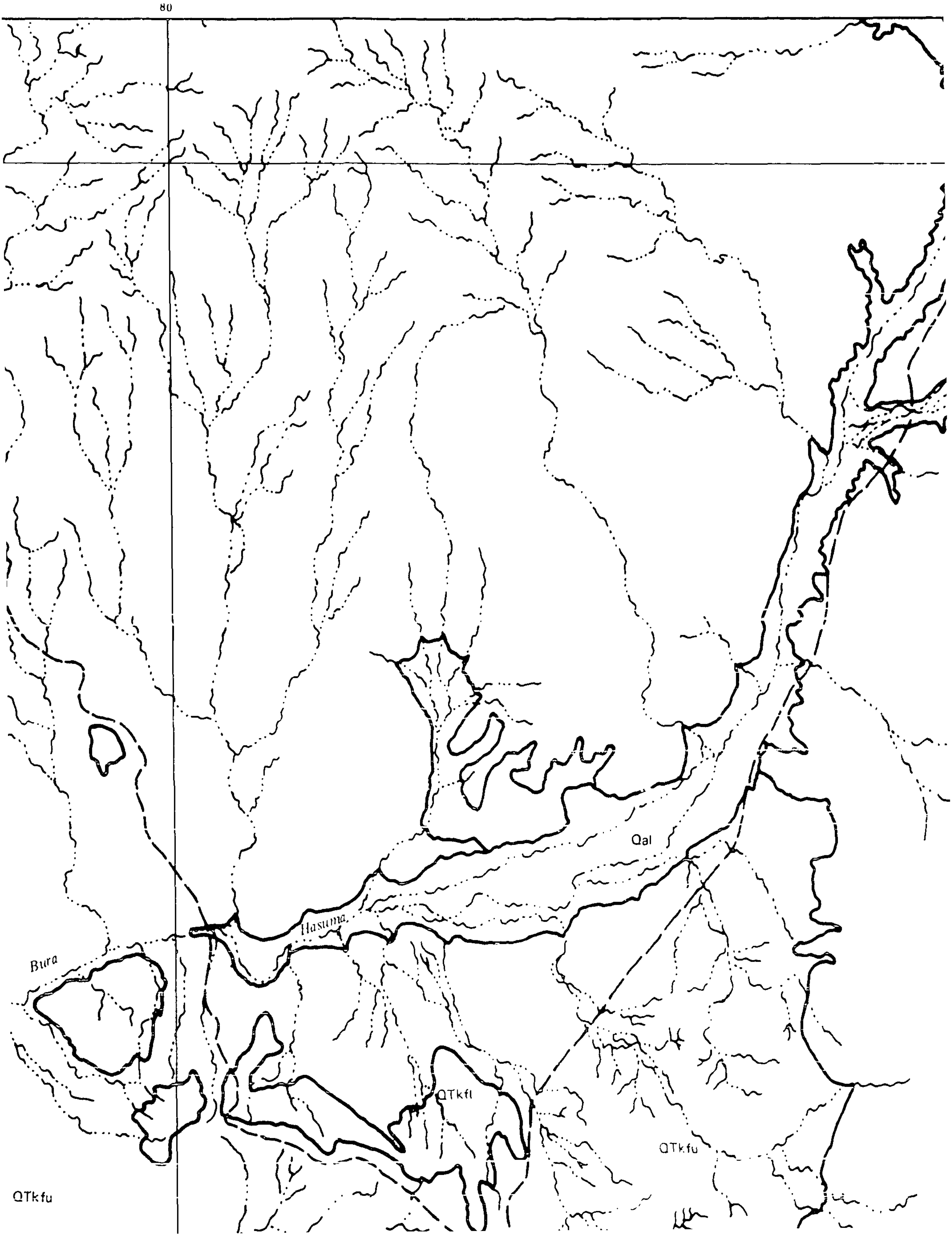

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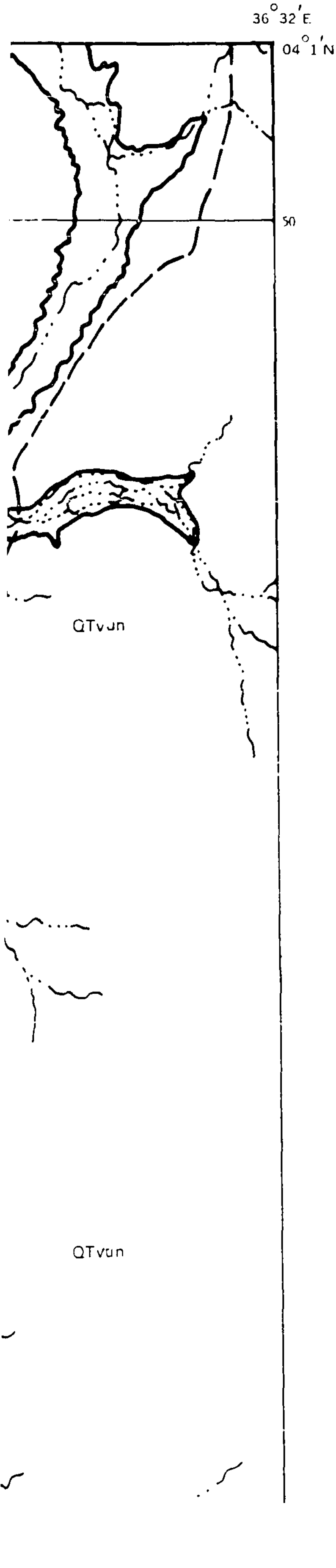

EXPLANATION

Recent

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Alluvium

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Qgb

Galana Boi beds

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Plio-Pleistocene

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QTkfu

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EXPLANATION

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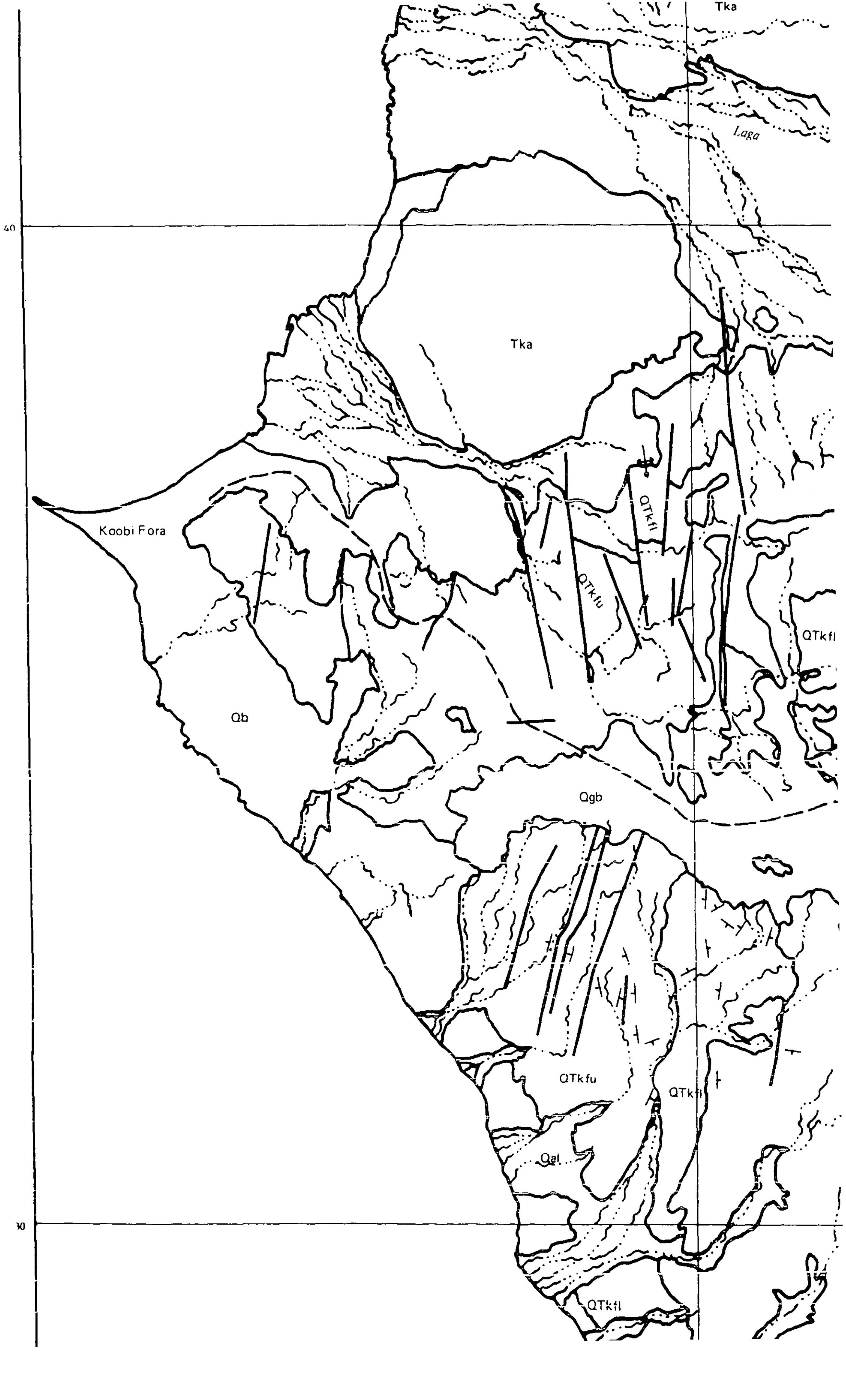

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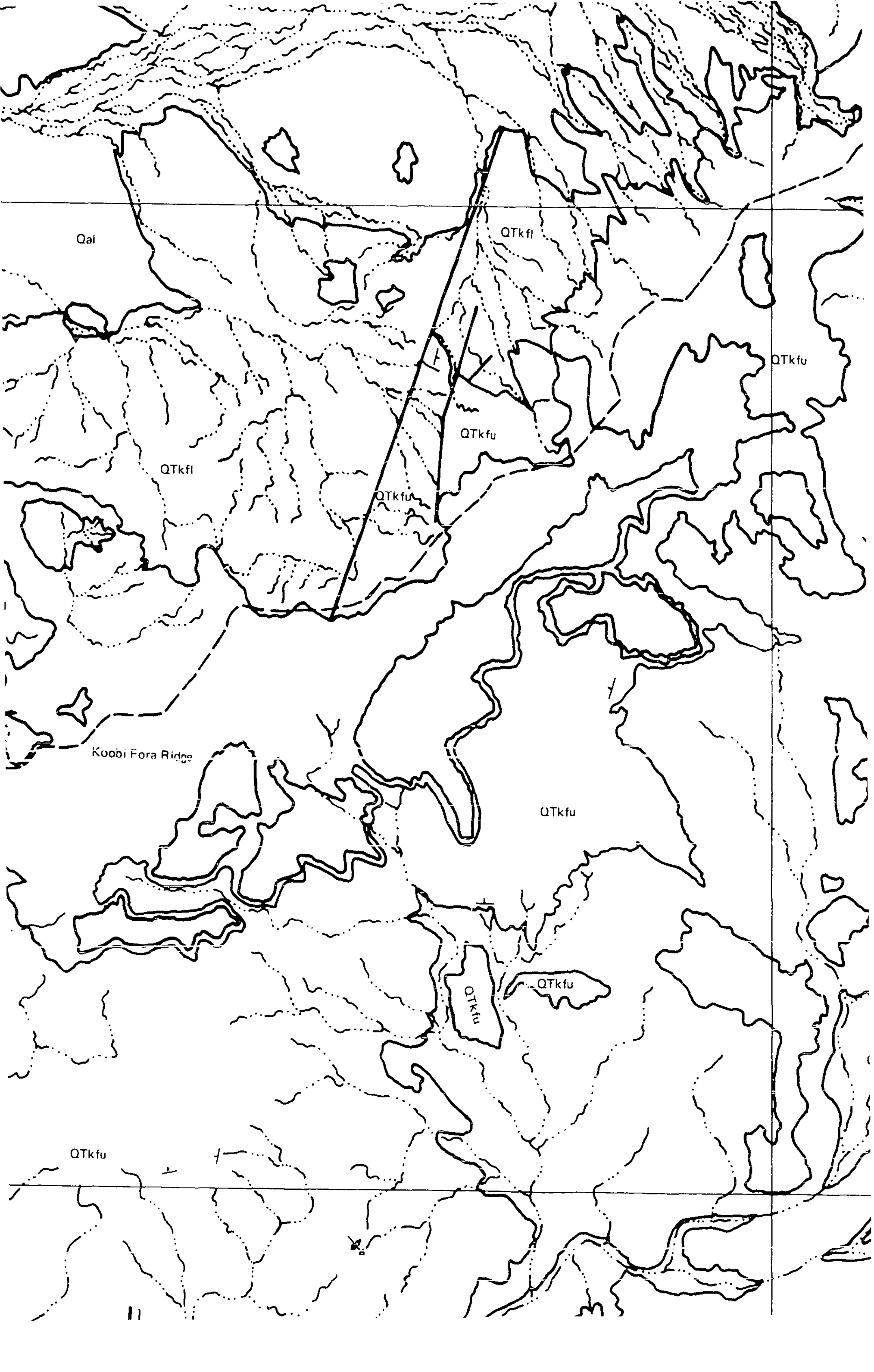
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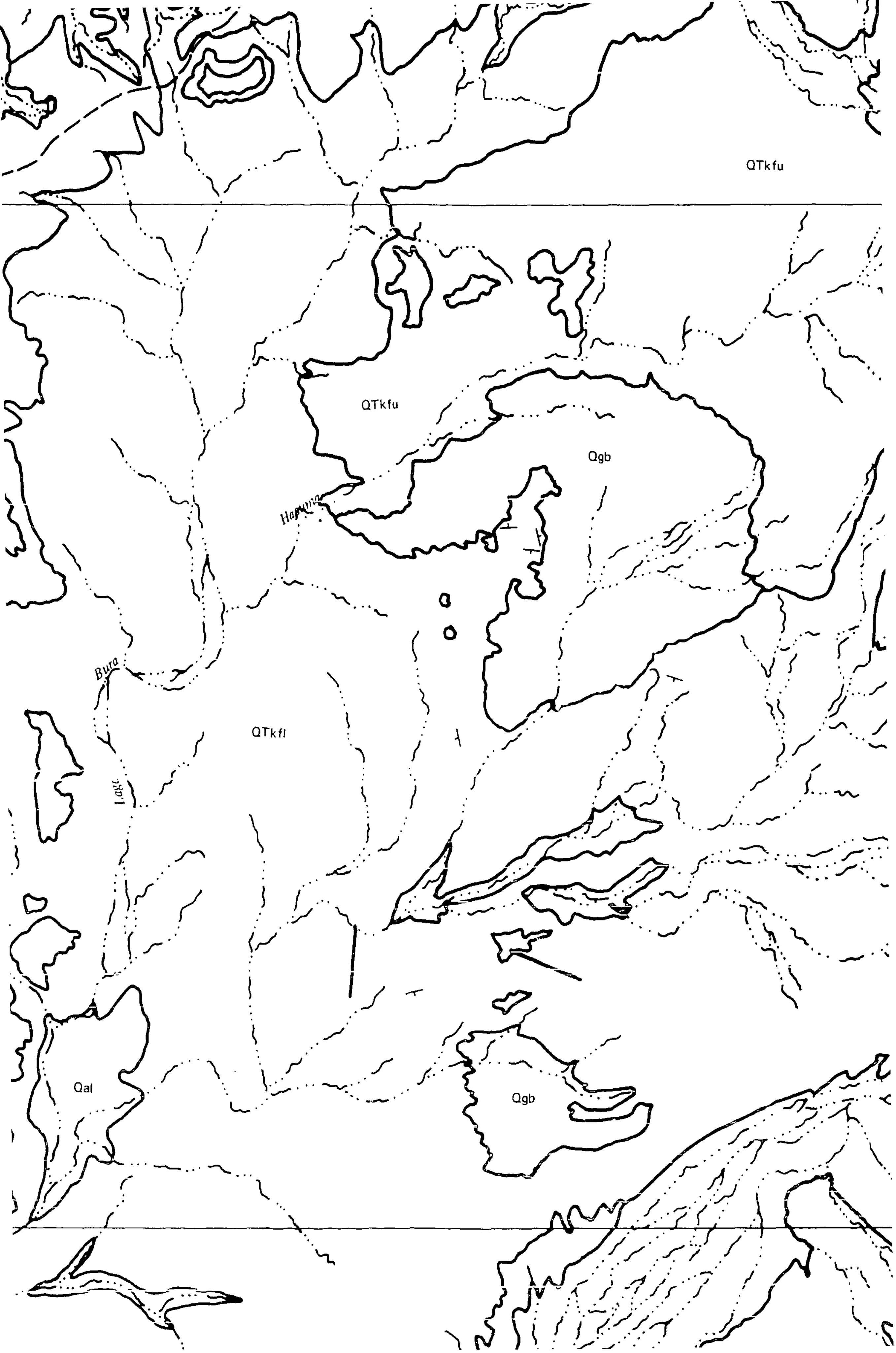

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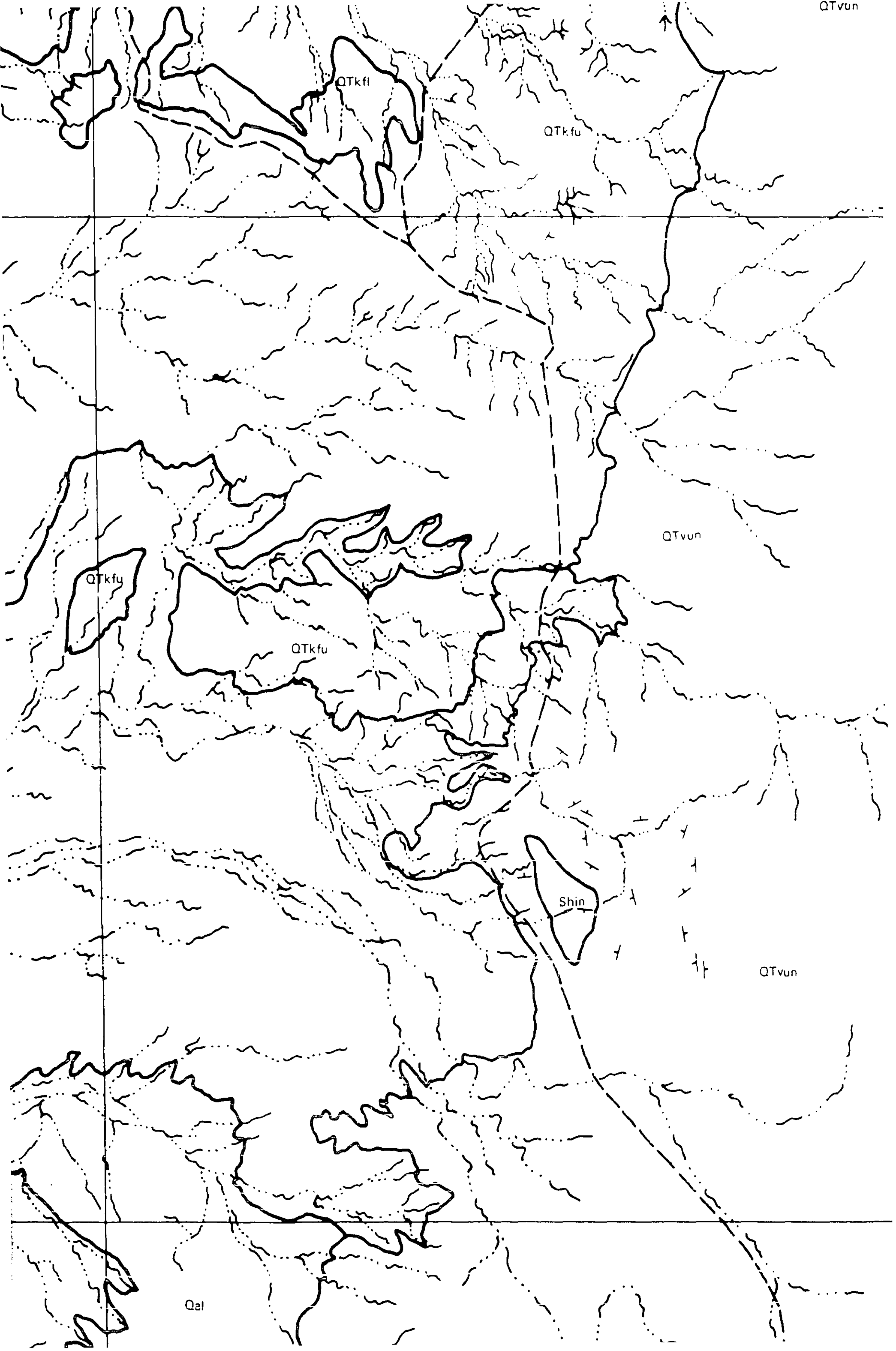
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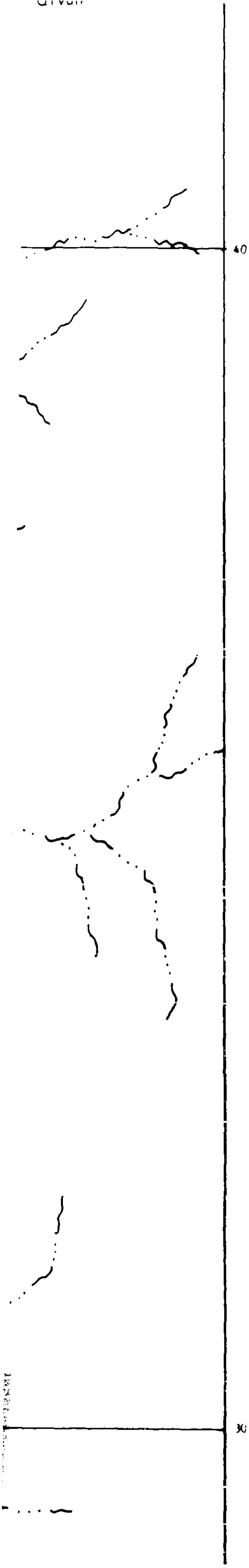

Plio-Pleistocene

Upper member, fluvial deposits of polymictic conglomerates, subarkoses and mudstones that grade laterally into fine-grained sandstones, siltstones, thin beds of algal stromatolites, fossiliferous limestones and tuffs. Thickness, 35 to 80 meters.

QTkfu

Lower member, limonitic, gypsiferous laminated siltstones, claystones, fossiliferous limestones, fine-grained sandstones intercalated with polymictic conglomerates and laminated tuffs. Thickness, 80 to 120 meters.

Pliocene

Tka

Kubi Algi Formation

Oligomictic conglomerates at base grade upward to fine-grained sandstones, cross-bedded tuffs, thin fossiliferous limestones and laminated limonitic siltstones. Sequence is capped by thinly laminated Suregei Tuff Complex. Thickness, 80 to 100 meters.

Miocene Pleistocene Undifferentiated

QTvun

Volcanics, undivided

Lava flows, ignimbrites, tuffs and intrusives of basaltic to rhyolitic composition intercalated with sediments and paleosols of Miocene and Pliocene age.

Contact

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Normal Fault

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QTkfu

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ercalated with sediments and paleosols of Miocene and
ocene age.

TERTIARY

Contact

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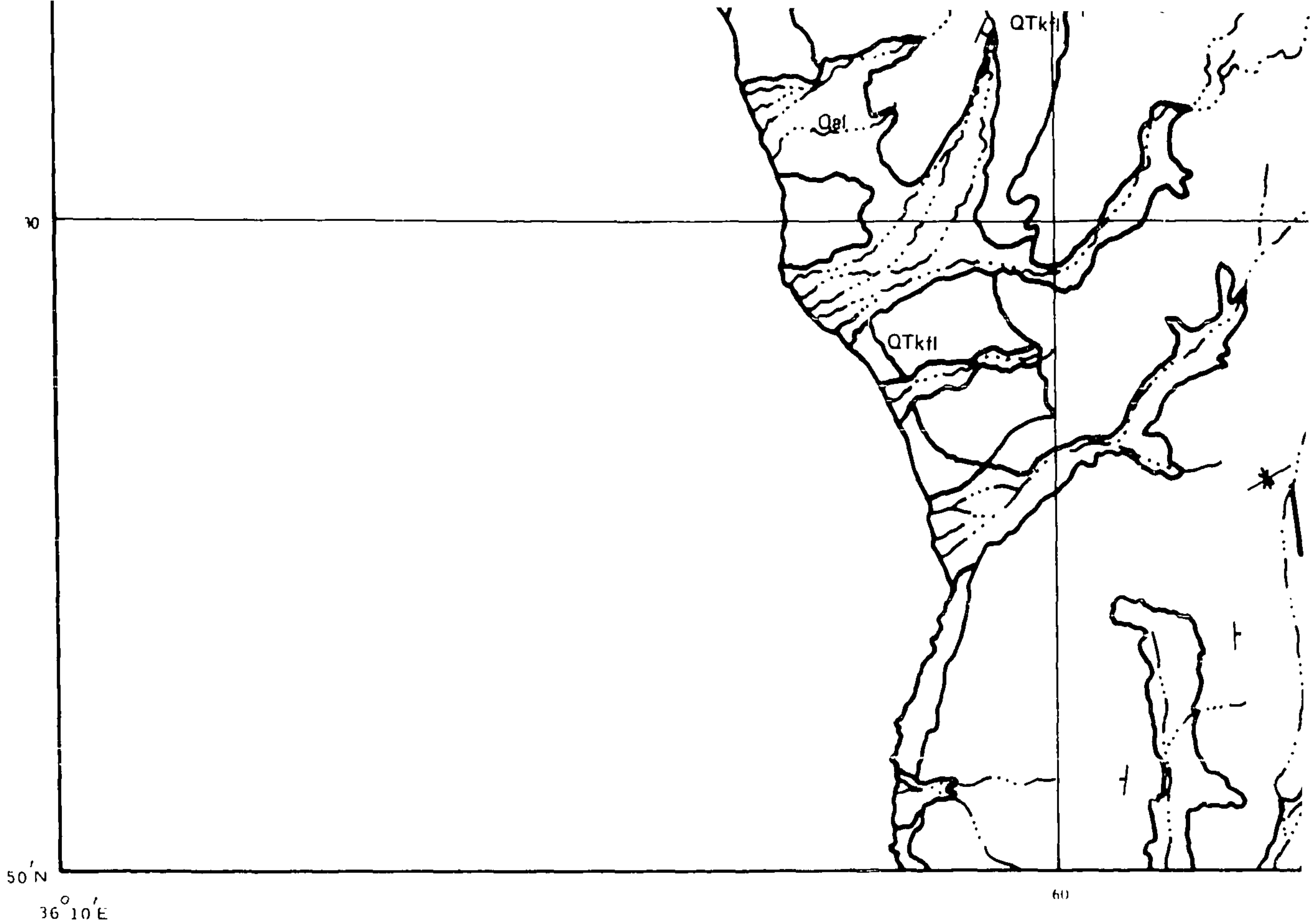
Normal Fault



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Qal
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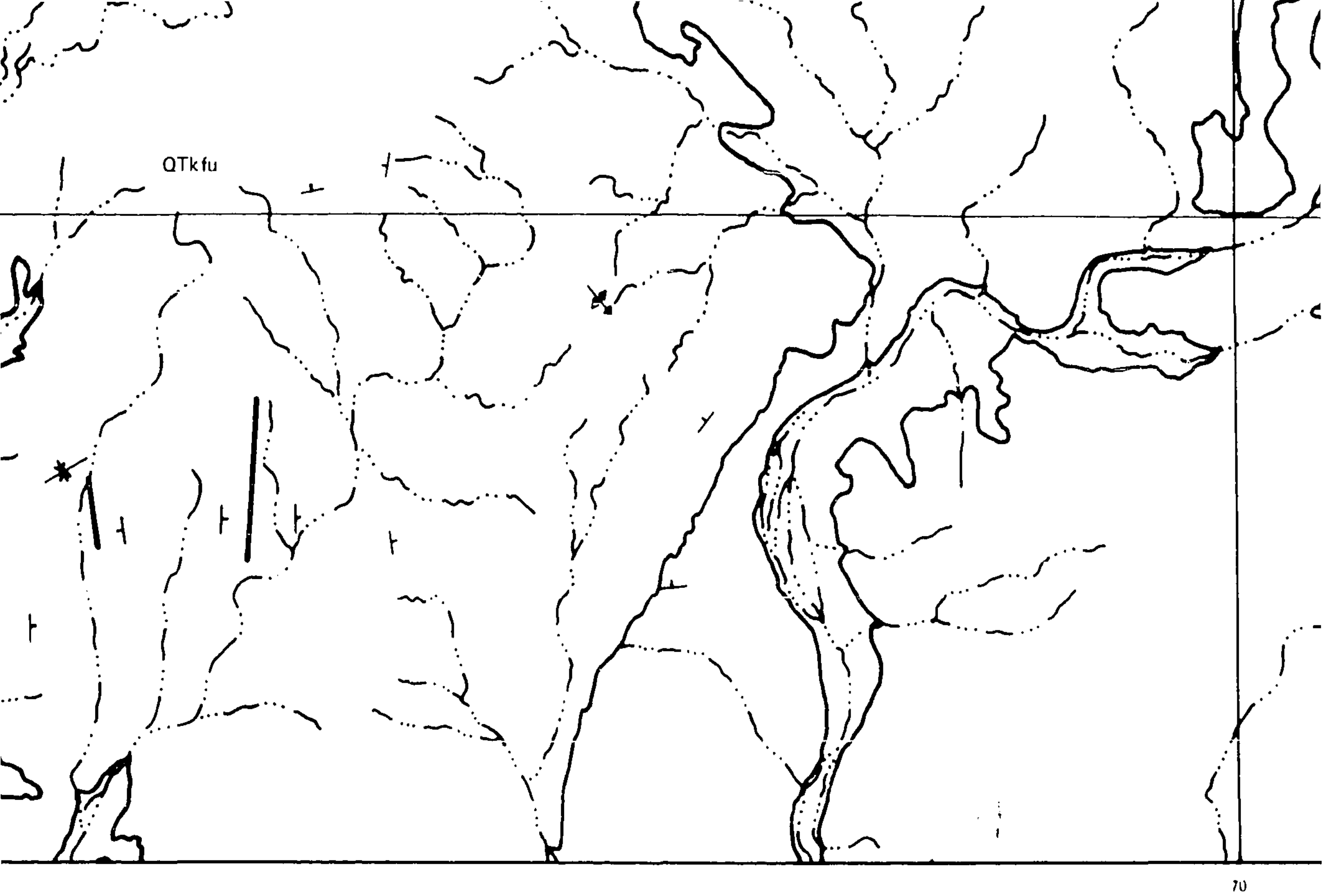
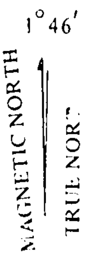
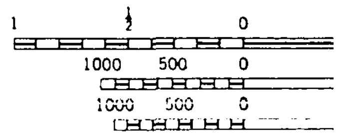
50'N
36°10'E
60



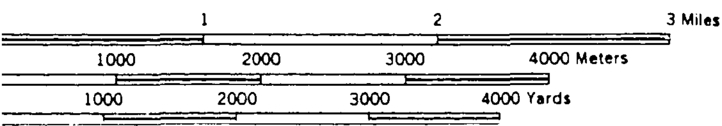


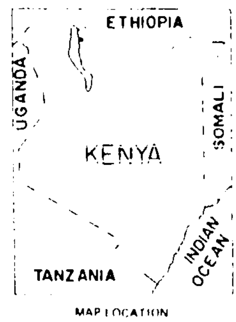
APPROXIMATE MEAN
DECLINATION, 1960



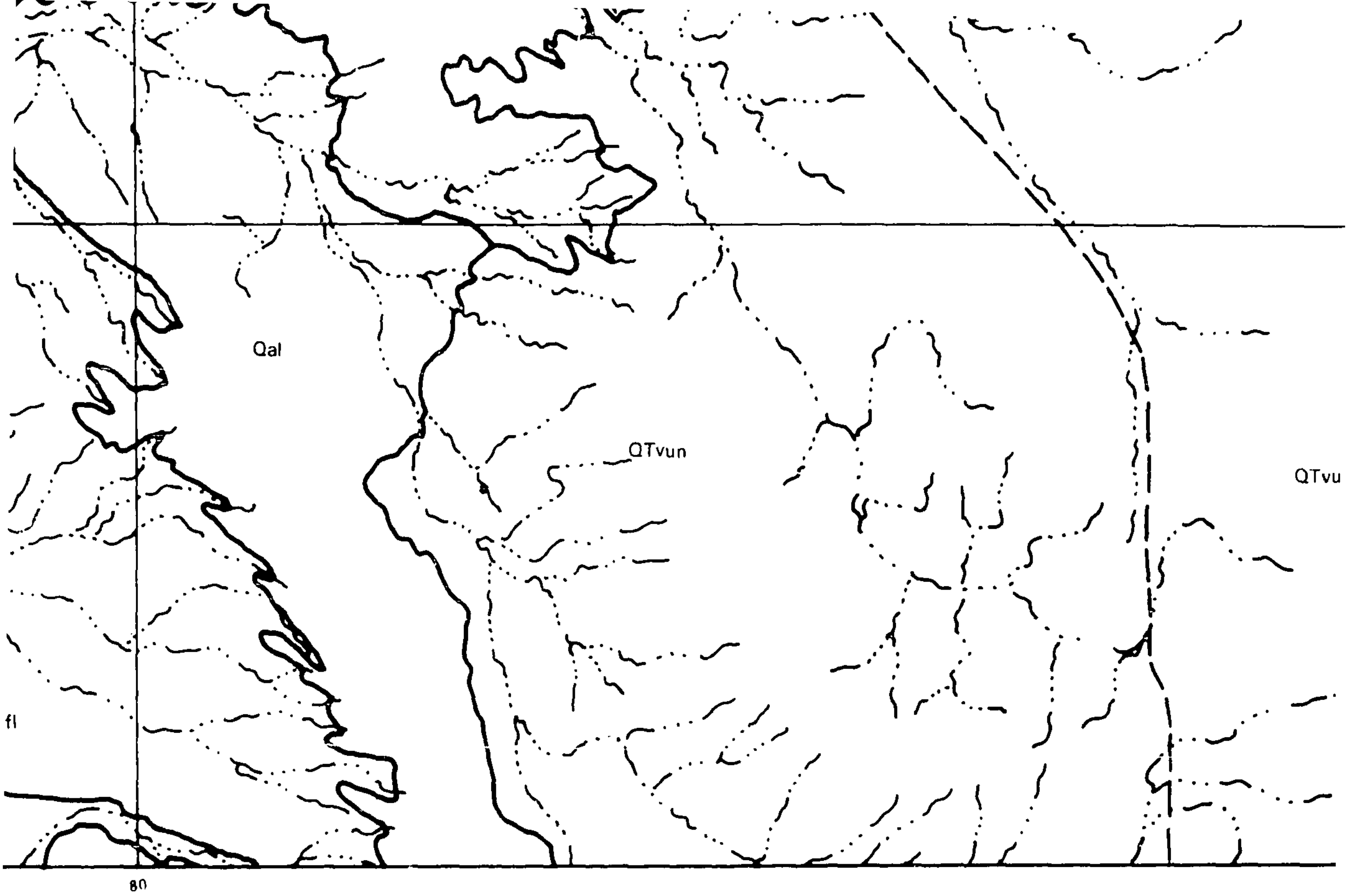
GEOLOGIC MAP OF THE KOO

SCALE 1:50 000





OBI FORA AREA, EAST RUDOLF, KENY



Geology mapped by B. E. B
field observations and aerial
in 1971, 1972 and 1973, as
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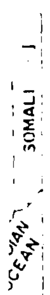
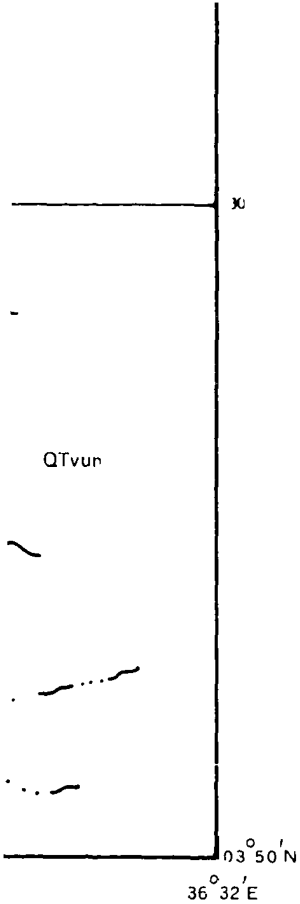


NYA



Contact

Normal Fault

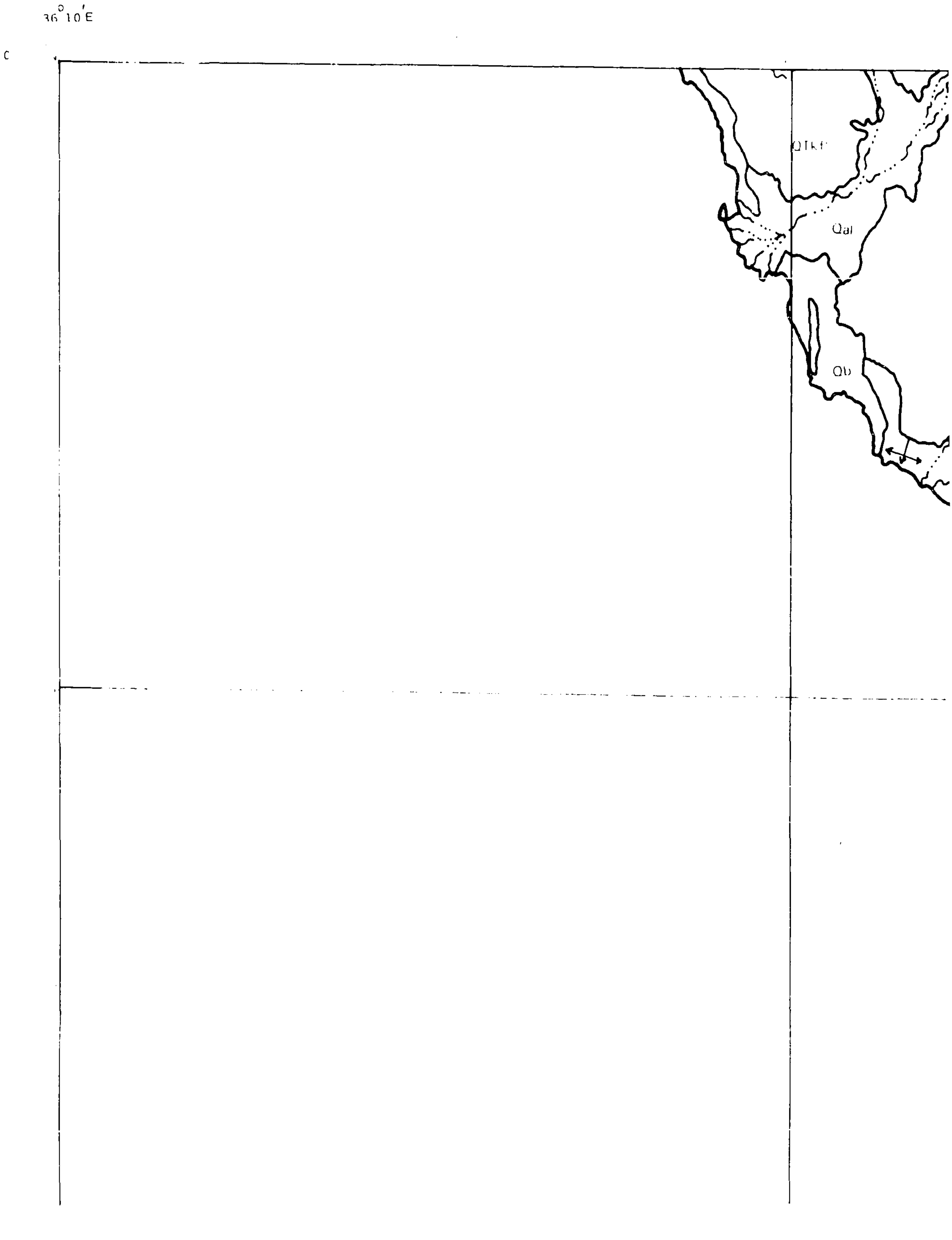
Axis of anticline

Axis of syncline

Strike and dip of beds

y B. E. Bowen from
ınd aerial photographs
1973, assisted by C. F.
d 1972, by T. E. Cerling

Fig. 3. Geologic map of the Allia Bay Area, East Rudolf, Kenya


36°10'E
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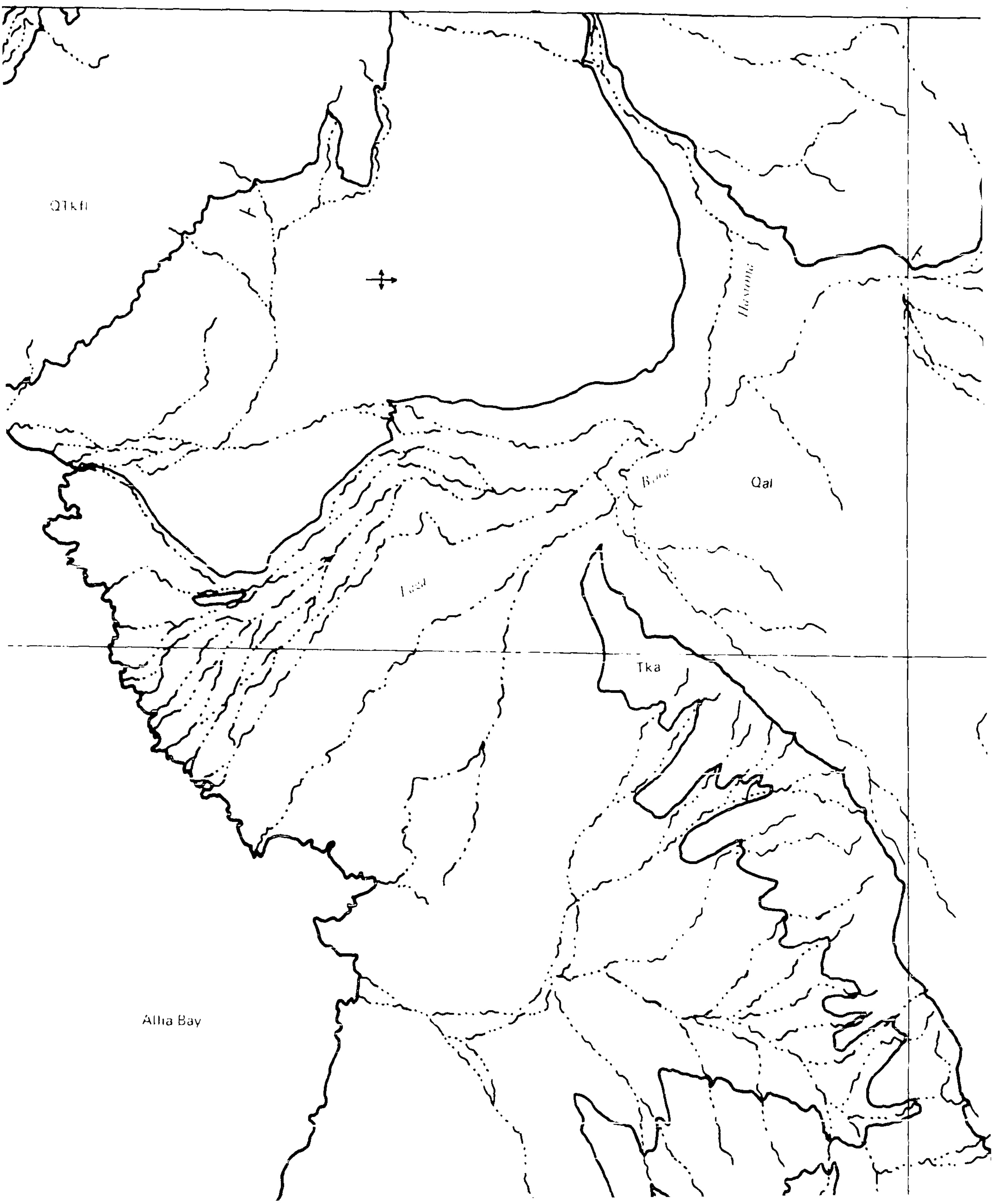
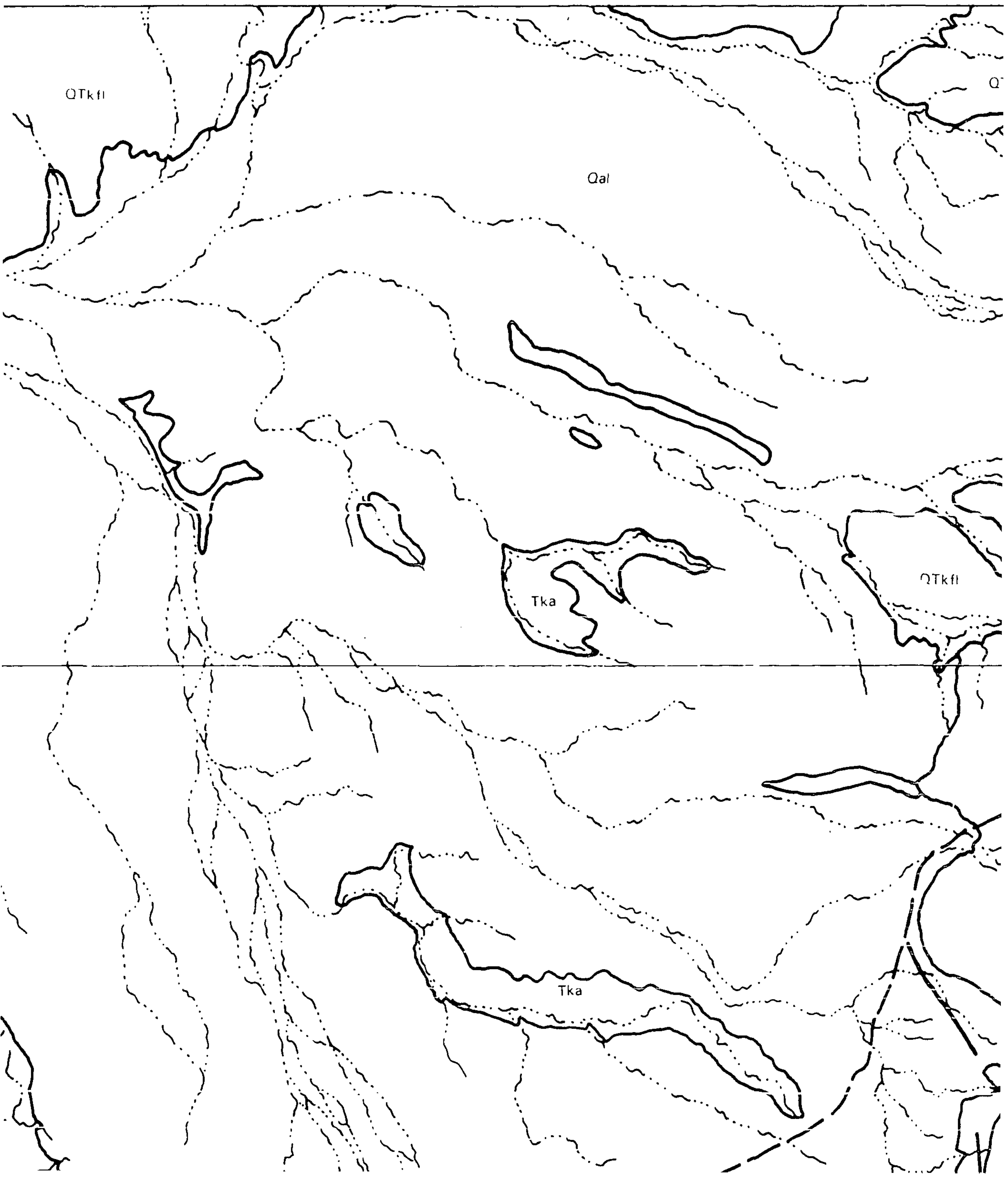
Qal
Qb


QTkfl
Qal
Tka
Allia Bay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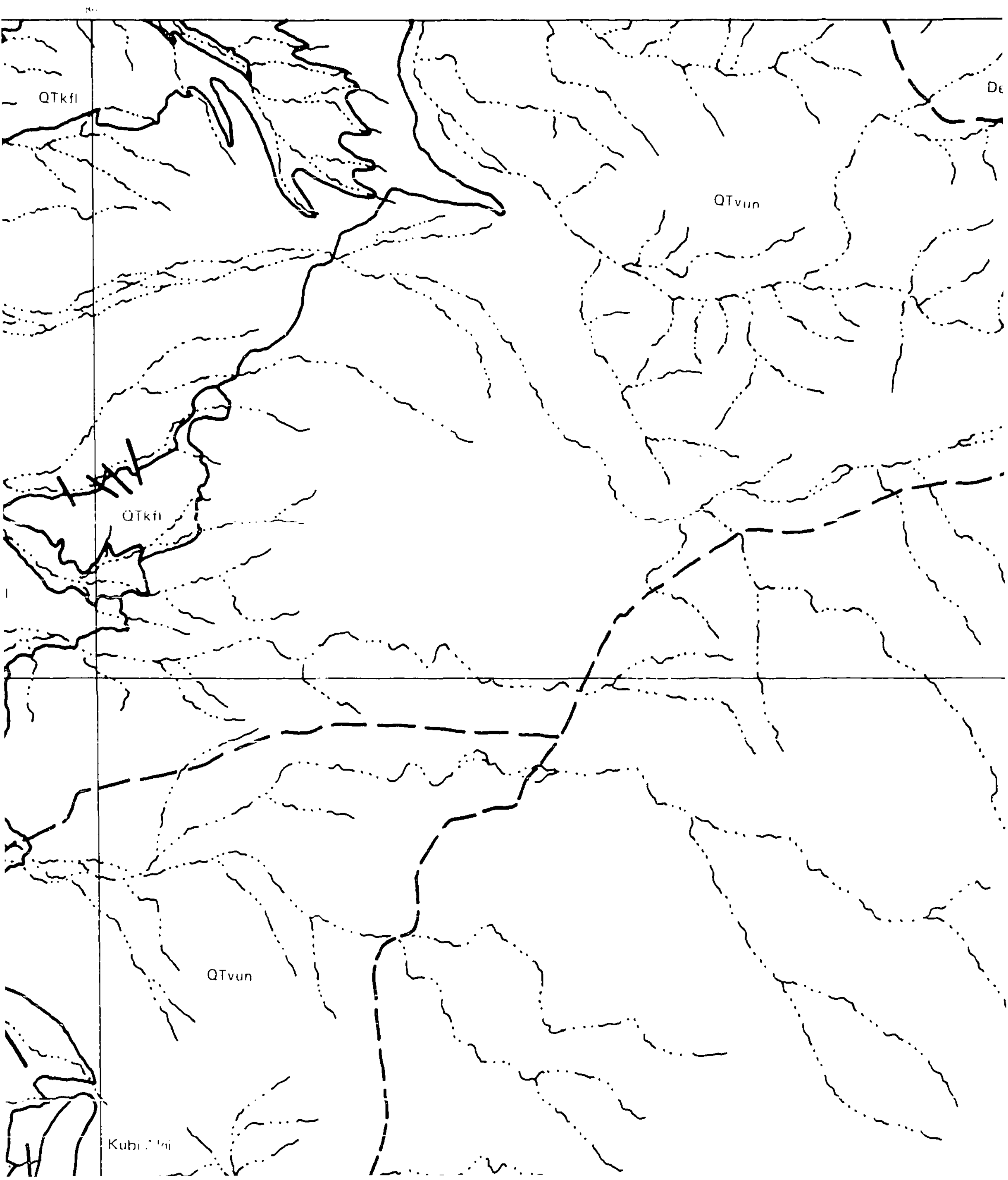
QTkfl
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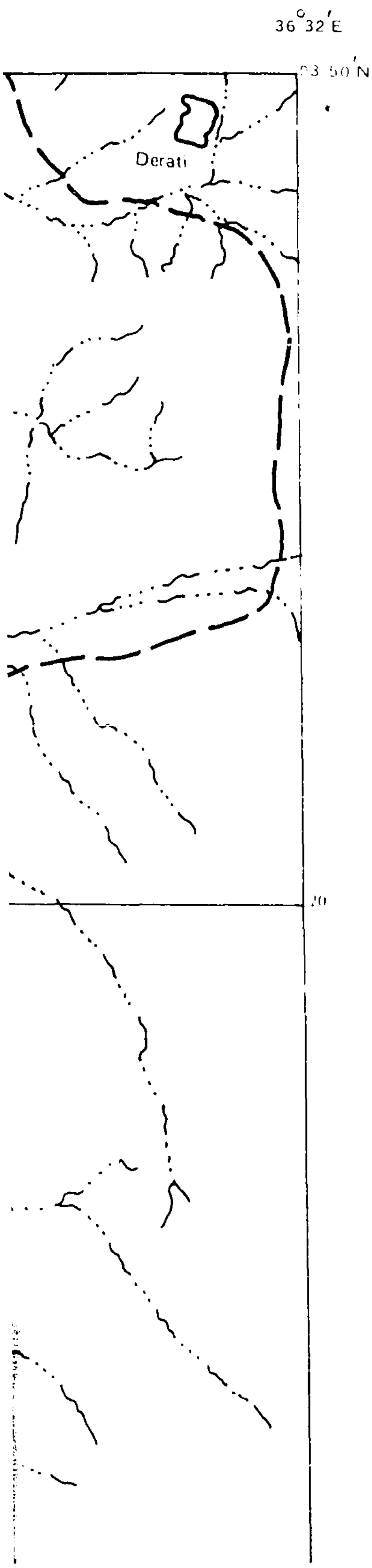
Kubi



EXPLANATION

Recent

Qal

Alluvium

Unconsolidated deposits of silt, sand, gravel, and cobbles along streams. Includes alluvial fans and terraces.

Unconsolic
alonç

Plio-Pleistocene

Koobi Fora Formation

Koobi Fora Formation consists of a series of laminated claystones, siltstones and fine-grained sandstones that are overlain by lenticular conglomerates, mudstones, thin beds of algal stromatolites, fossiliferous limestones and tuffs. Thickness, 180 to 200 meters.

QTkfl

Lower member, limonitic, gypsiferous laminated siltstones, claystones, fossiliferous limestones, fine-grained sandstones intercalated with polymictic conglomerates and laminated tuffs. Thickness, 80 to 120 meters.

EXPLANATION

Qal

Alluvium

ted deposits of silt, sand, gravel,
bbles along streams. Includes alluvial
ıd terraces.

Qb

Beach Sand

Unconsolidated deposits of fine sand in beach ridges along the present shoreline.

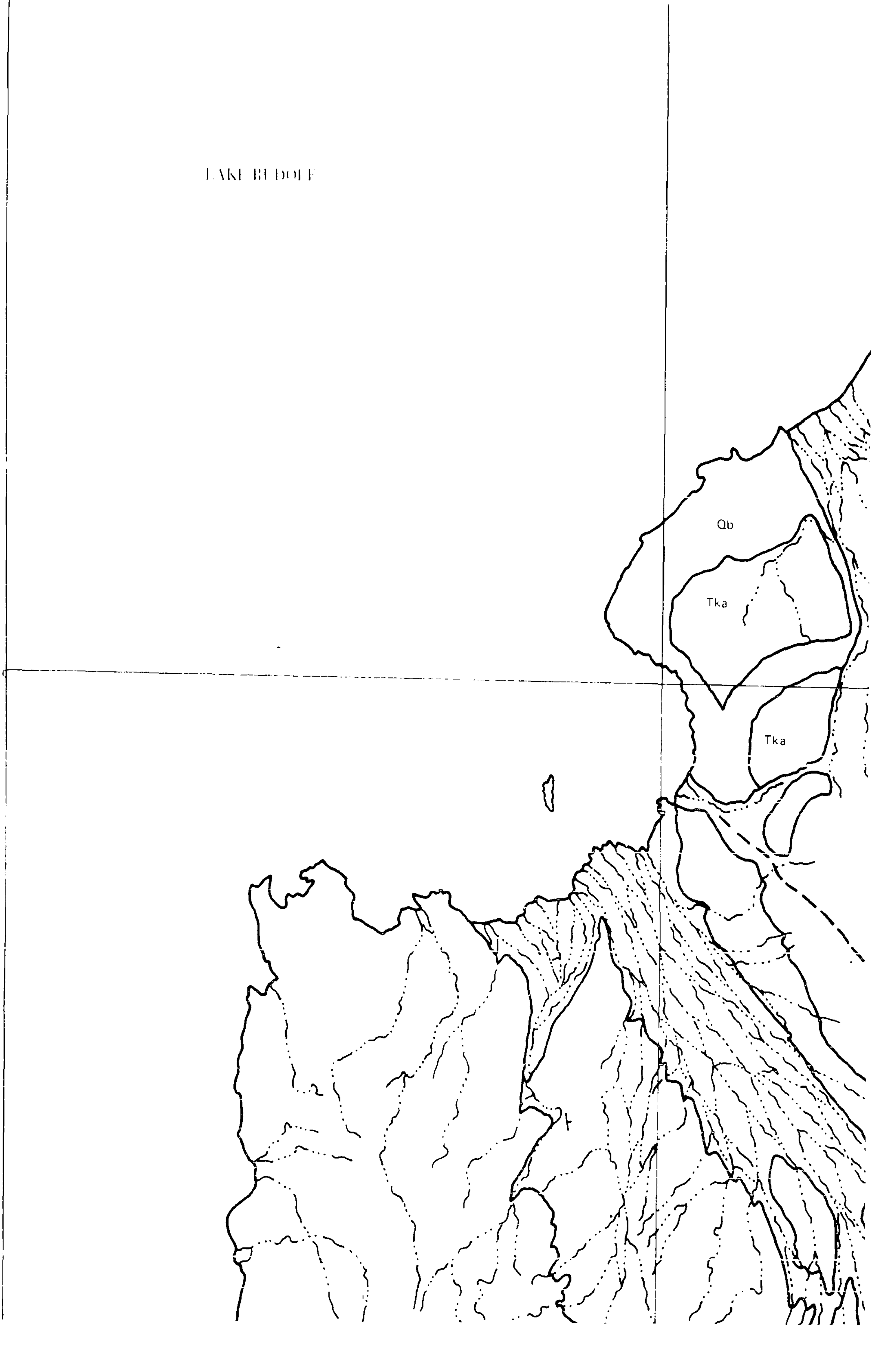
QUATERNARY

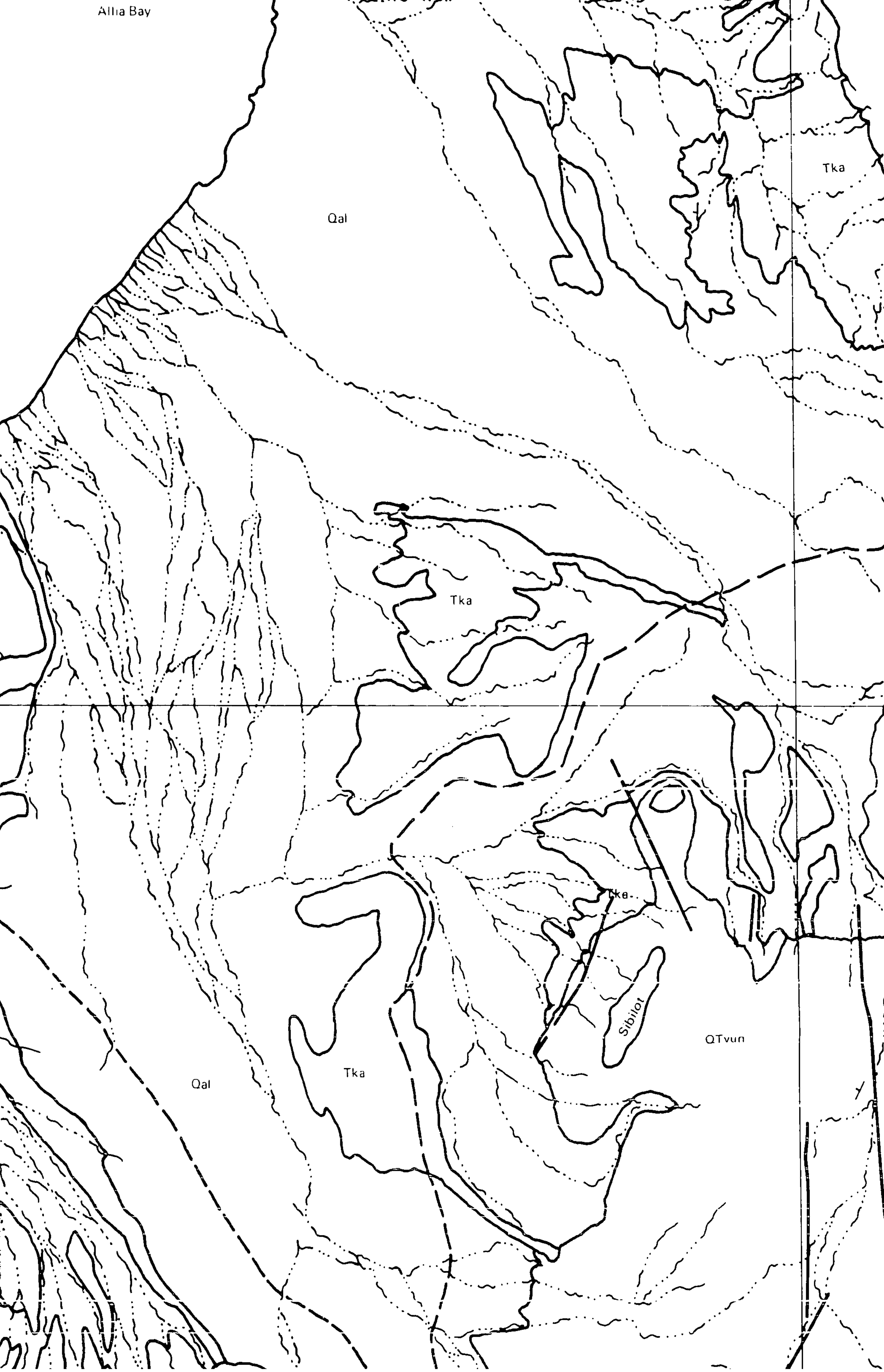
Koobi Fora Formation

Formation consists of a series of laminated
ɔnes, siltstones and fine-grained sandstones
e overlain by lenticular conglomerates,
ɔnes, thin beds of algal stromatolites,
erous limestones and tuffs. Thickness,
200 meters.

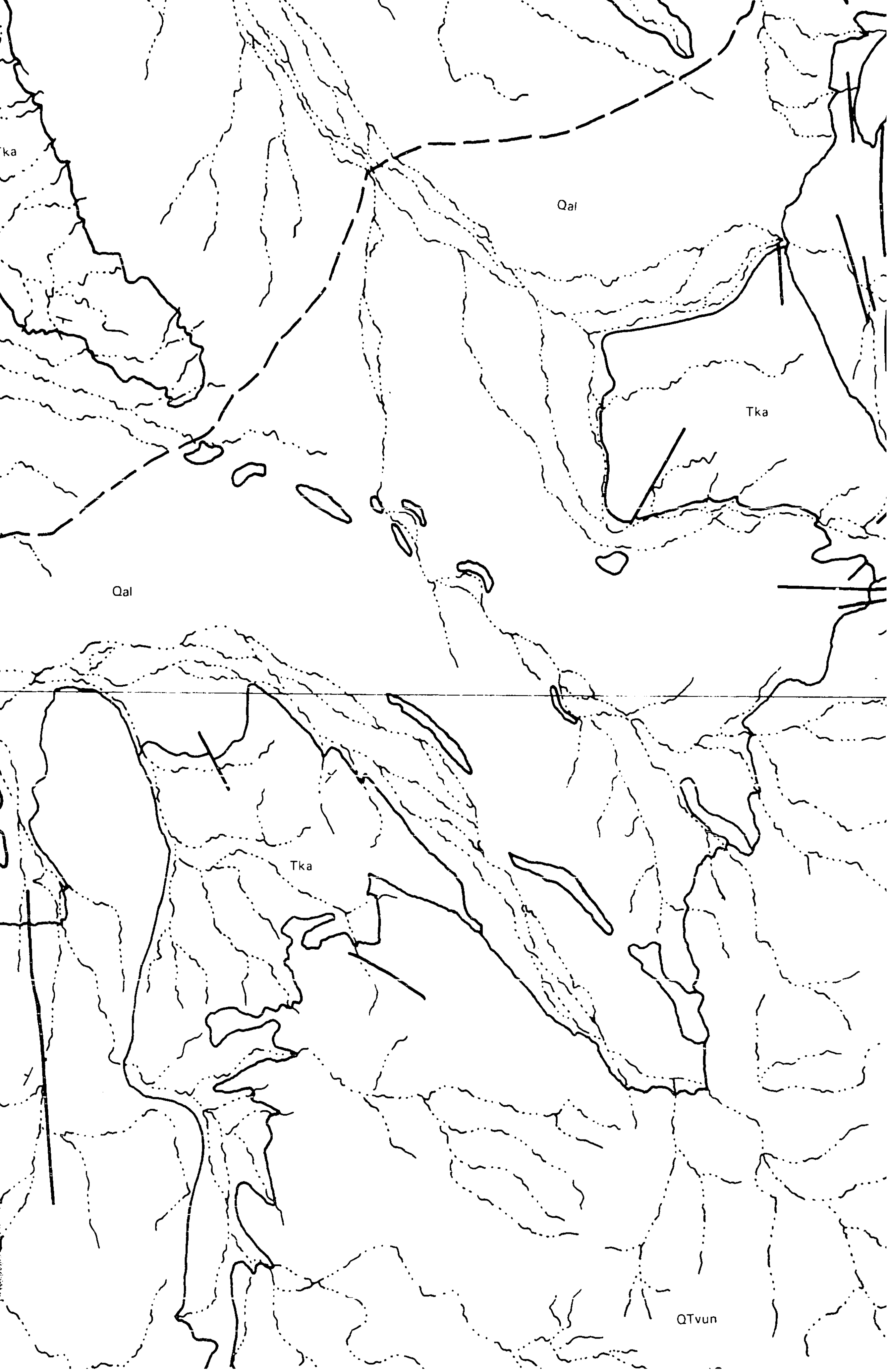
QTkfl

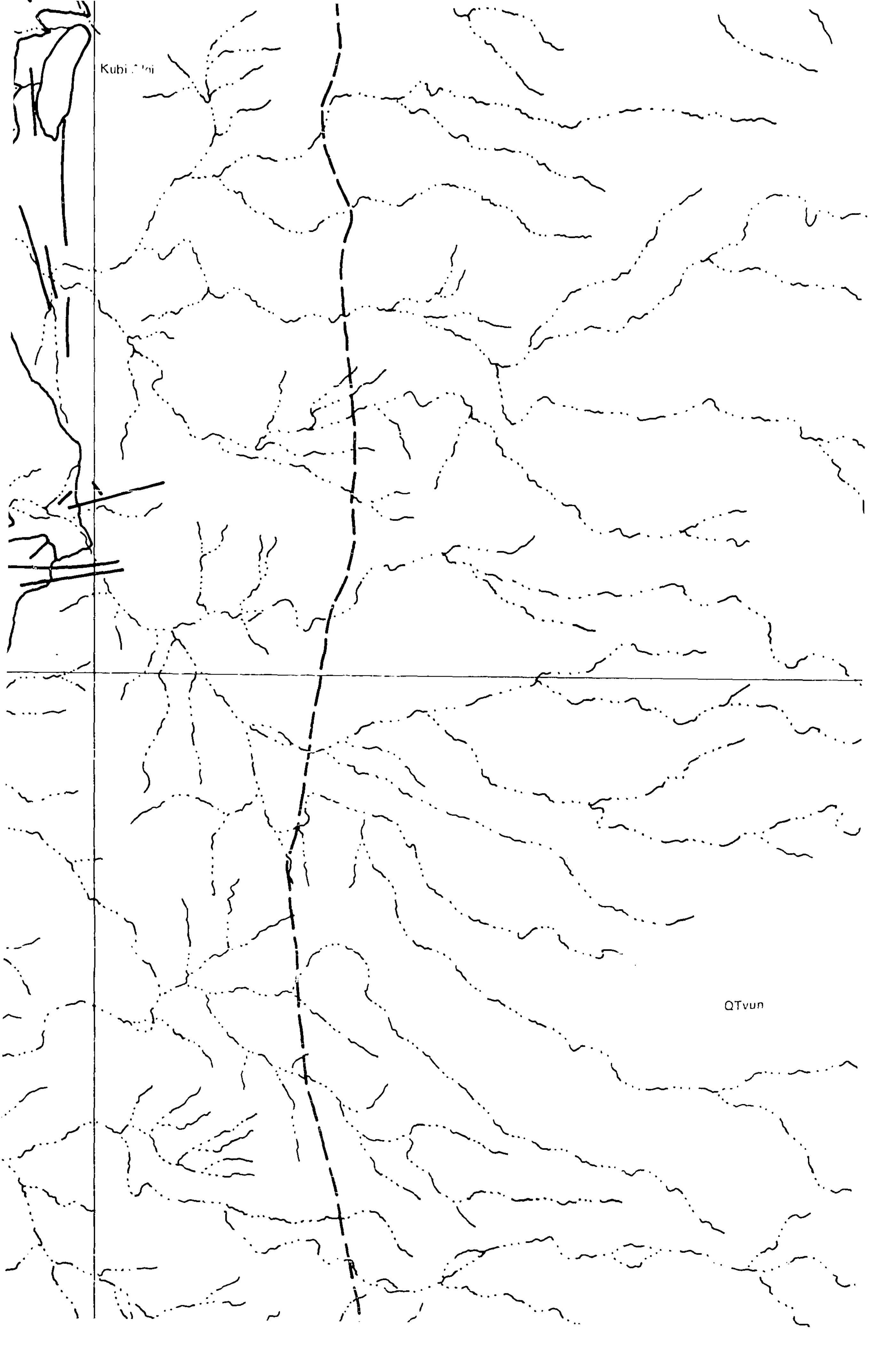
mber, limonitic, gypsiferous laminated siltstones,
stones, fossiliferous limestones, fine-
ned sandstones intercalated with polymictic
lomerates and laminated tuffs. Thickness,
o 120 meters.

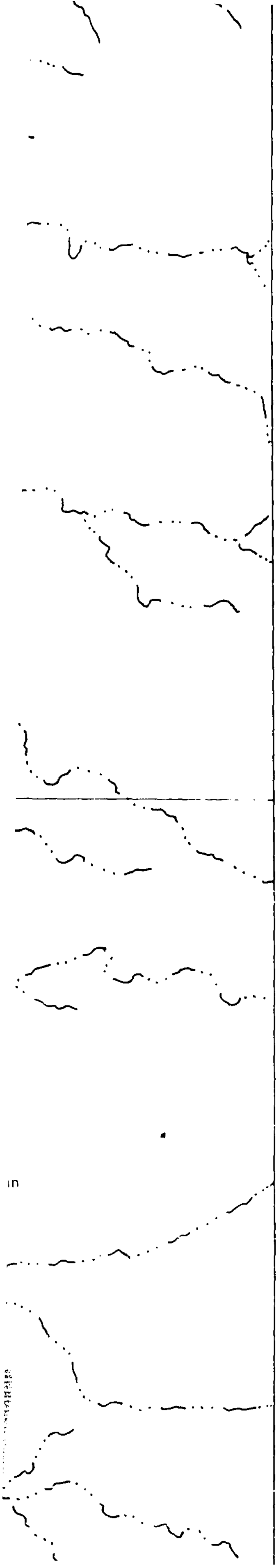

LAKE RUDOLF
Qb
Tka
Tka



Allia Bay
Qal
Tka
Tka
Tka
Tka
Qal
Sibilot
QTvun


Tka
Qal
Tka
Qal
Tka
QTvun


Kubi
QTvun



claystones, fossiliferous limestones, fine-grained sandstones intercalated with polymictic conglomerates and laminated tuffs. Thickness, 80 to 120 meters.

Pliocene

Tka

Kubi Algi Formation

Oligomictic conglomerates at base grade upward to fine-grained sandstones, cross-bedded tuffs, thin fossiliferous limestones and laminated limonitic siltstones. Sequence is capped by thinly laminated Suregei Tuff Complex. Thickness, 80 to 100 meters.

Miocene - Pleistocene Undifferentiated

QTvun

Volcanics, undivided

Lava flows, ignimbrites, tuffs and intrusives of basaltic to rhyolitic compositio intercalated with sediments and paleosols of Miocene and Pliocene age.

Contact

No

claystones, fossiliferous limestones, fine-grained sandstones intercalated with polymictic conglomerates and laminated tuffs. Thickness, 80 to 120 meters.

TERTIARY

Tka

Kubi Algi Formation

ligomictic conglomerates at base grade upward to fine-grained sandstones, cross-bedded tuffs, thin fossiliferous limestones and laminated limonitic siltstones. Sequence is capped by thinly laminated Suregei Tuff Complex. Thickness, 80 to 100 meters.

QTvun

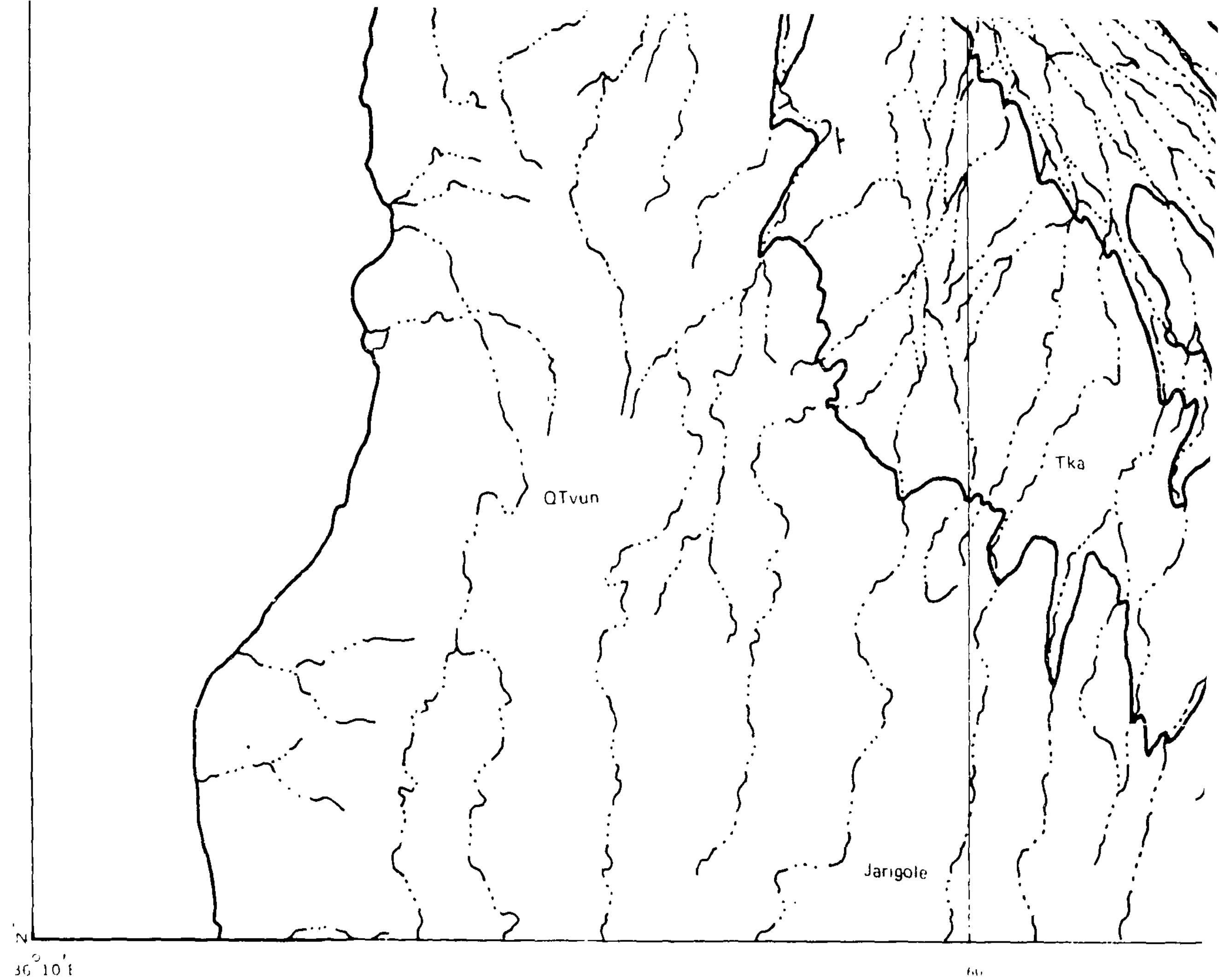
Volcanics, undivided

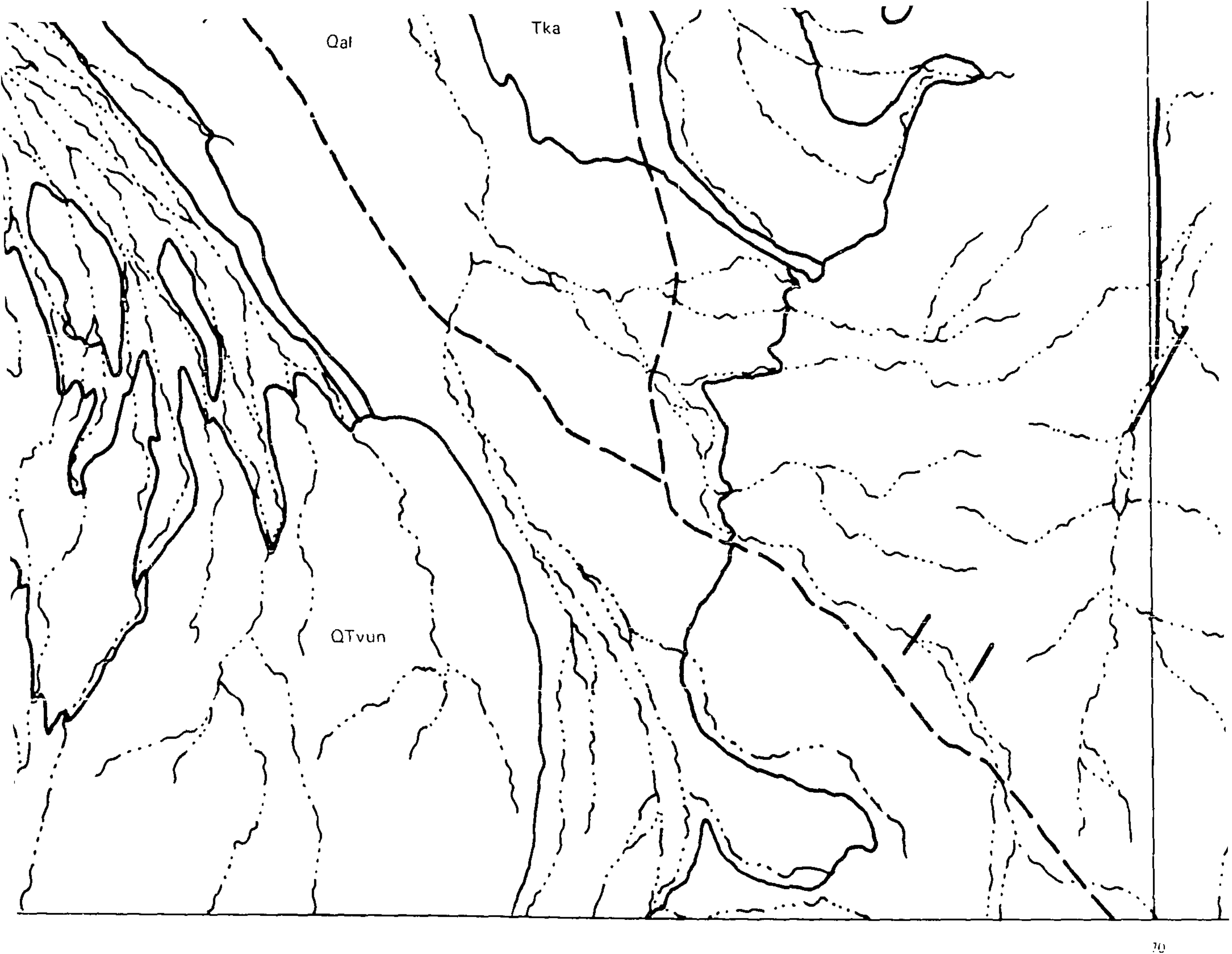
.ava flows, ignimbrites, tuffs and intrusives of basaltic to rhyolitic composition intercalated with sediments and paleosols of Miocene and Pliocene age.

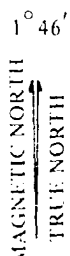
Contact

U
D

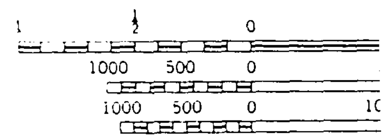
Normal Fault


QTvun
Tka
Jarigole
36° 10' E

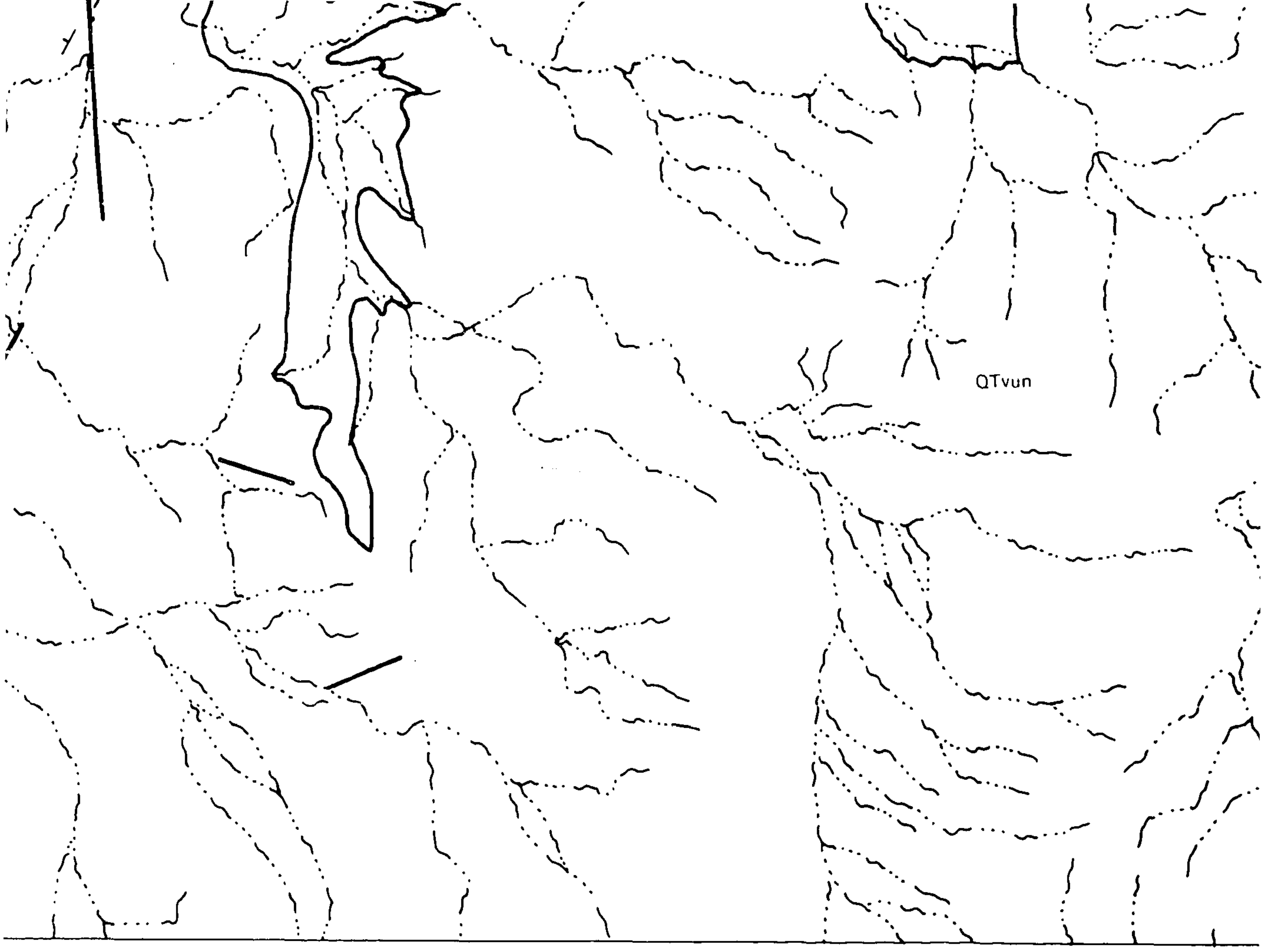




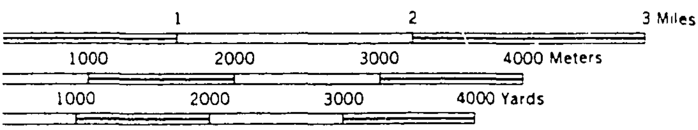
APPROXIMATE MEAN
DECLINATION, 1960

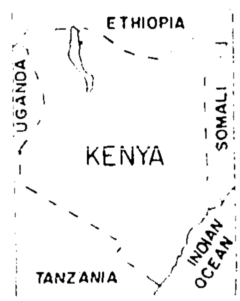


GEOLOGIC MAP OF THE ALLIA

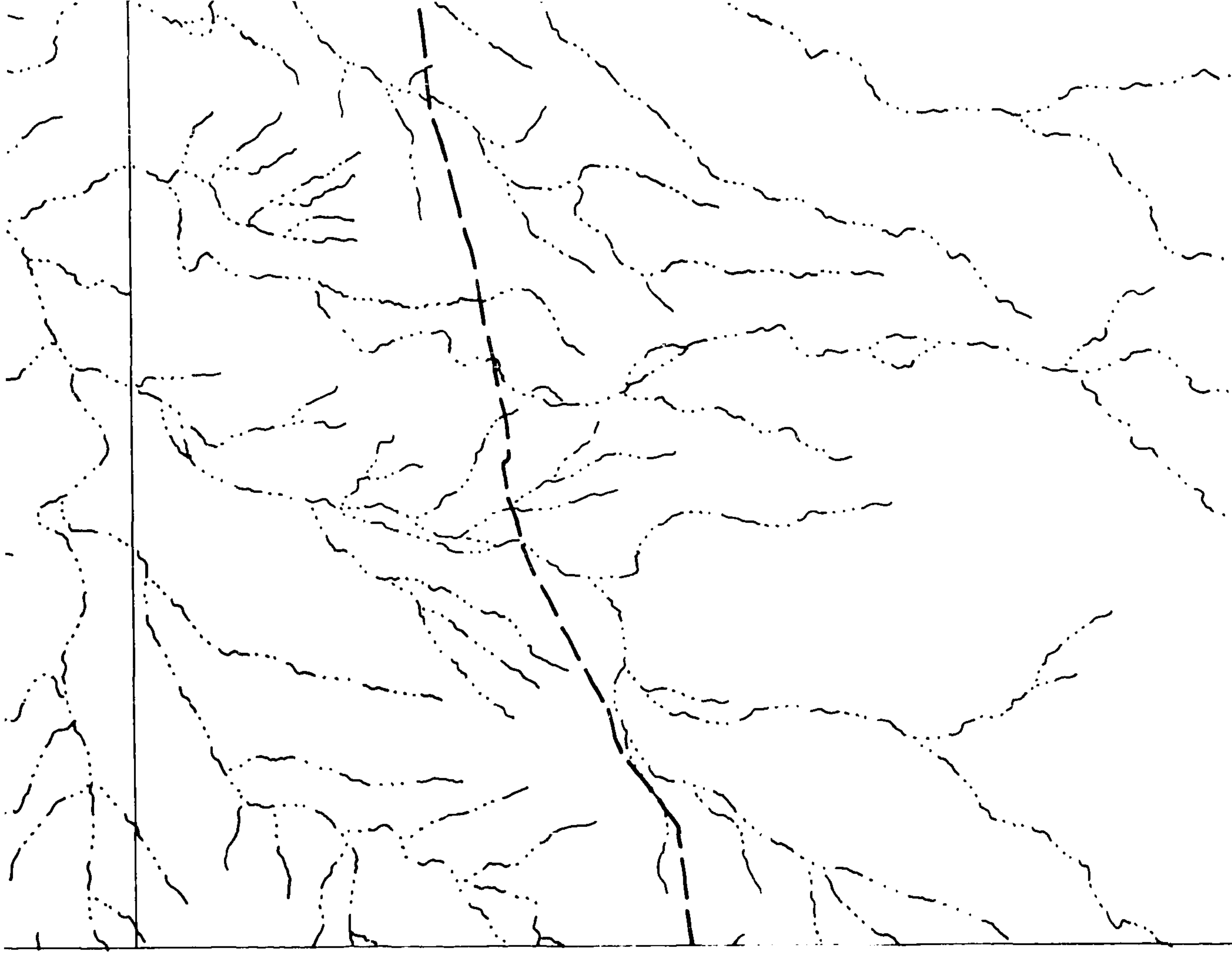


SCALE 1:50 000

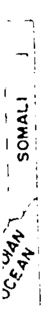




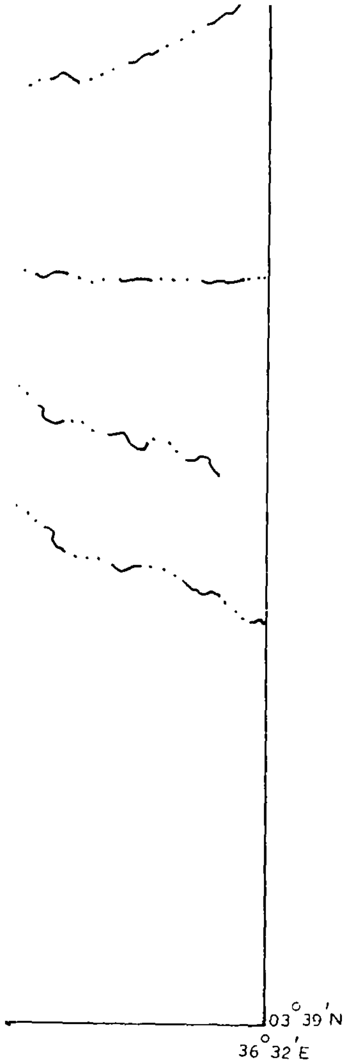
IA BAY AREA, EAST RUDOLF, KENYA



Geology mapped by
H. Acuff from field
aerial photographs i
C. F. Vondra.



A



Contact

Normal Fau

Axis of anticline

Axis of syn

Strike and dip of beds

apped by B. E. Bowen and by
om field observations and
ographs in 1972, assisted by
a.

Detailed laboratory analyses of the samples collected in the Ileret and Koobi Fora areas have been carried out to supplement the field work and to provide a basis for paleoenvironmental interpretations. The petrology of the sediments in the Allia Bay constitutes a separate study and will be reported at a later date. One hundred fifty sedimentary and volcanic units were thin-sectioned and composition of framework grains of the sediments was obtained from 300 point counts per thin section. Additional mineralogical data was acquired through sediment disaggregation and mineral segregation using bromoform-toluene mixtures to give a variety of specific gravities. Textural parameters for 129 sandstones and siltstones were derived from distribution data obtained from sieve and pipette analysis. The statistical measures of mean size, standard deviation, skewness and kurtosis were calculated using moment statistics.

Textural parameters were also calculated for 51 siltstones and mudstones. Standard x-ray diffraction methods were applied to these samples. In addition, free iron, aluminum and manganese were measured in two vertical profiles identified in the field as possible paleosols. The 40 centimeter profiles were sampled at 5 centimeter intervals. Free iron, aluminum and manganese, defined as the amount extractable from disaggregated claystone by the sodium citrate-sodium hydrosulfite method (Holmgren, 1967) were analyzed with a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer.

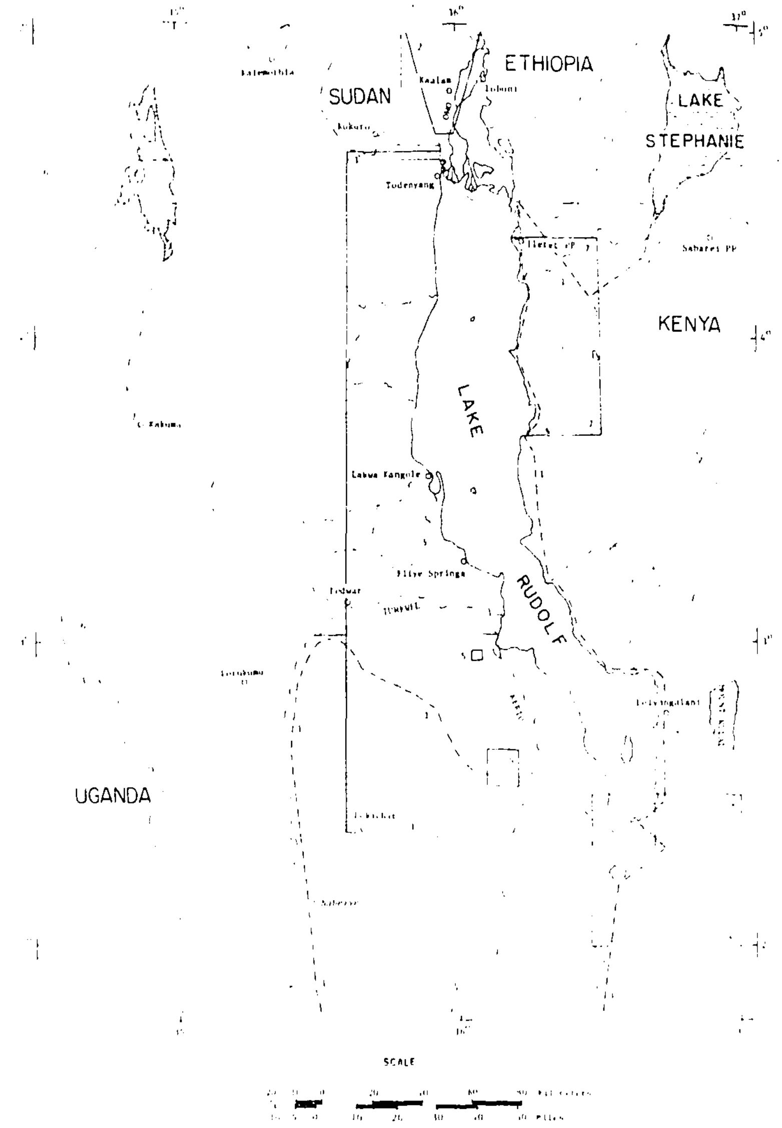
Review of Previous Work

Although many expeditions have traversed the region northeast of Lake Rudolf since its European discovery by Count Teleki in 1888 little geologic data have been collected (Hohnel, 1894; Smith, 1900; Harrison, 1901 and Athill, 1920). Based on the data collected by the Teleki Expedition, Suess (Hohnel et al., 1891) first recognized the paleontologic and geologic significance of the Lake Rudolf area. He suggested that the continuation of the "Red Sea fractures" extended southwestward along the African chain of lakes rather than along the African coast. He also recognized the significance of the nilotic fauna in the lake.

The Cambridge Expedition of 1930 made a few preliminary geological observations but was mainly concerned with the biology of the region west of the lake. The Lake Rudolf Rift Valley Expedition of 1934 made a somewhat detailed survey of a portion of Turkana Province on the west side of the lake and presented a geologic map of that area (Fuchs, 1934; 1939) (Fig. 4). However the expedition made only a brief reconnaissance of the area east of the lake (Fuchs, 1934; 1939).

In 1932 Arambourg (1935) led an expedition to the Omo River Valley north of the lake to investigate fossiliferous Upper Cenozoic exposures first discovered by Brumpt of the Bourg du Bozas Omo Expedition in 1902. This became the impetus for the 1967 International Paleontological Research Expedition to the Omo Valley (Butzer and Thurber, 1969; Howell, 1968 and Leakey et al., 1969). As a result of this expedition, the

Fig. 4. Index map to previous studies



Numbers keyed to list of previous studies. Complete references are listed at end of [illegible]

1. [illegible], 1962.
2. Arambourg, C., 1935 and Howell, [illegible], 1968.
3. Fuchs, V. E., 1939.
4. Dodson, R. [illegible], 1963.
5. Patterson, B., 1966.
6. Walsh, J. and Dodson, R. [illegible], 1969.
7. Present Study.

INDEX MAP TO PREVIOUS STUDIES

relatively complete Upper Cenozoic sedimentary sequence exposed in the Omo basin has been differentiated (Butzer and Thurber, 1969), the sediments have been studied in detail and paleoenvironmental interpretations have been presented (Leakey et al., 1969; Butzer et al., 1969; Heinzelin and Brown, 1969 and Heinzelin et al., 1971).

Geologic mapping of the southern end of the Lake Rudolf area was initiated by the Geological Survey of Kenya in 1956 (Dodson, 1963). The survey extended only as far north as the southern slopes of Mount Kulal on the east side and the Loriyu Plateau on the west side (2°30' N) (Fig. 4). A reconnaissance survey was later carried out on the west side of the lake from the mouth of the Turkwel River (3° N) to just north of the Turkana village of Todenyang (4°40' N)(Walsh and Dodson, 1969)(Fig. 4).

This investigation is an outgrowth of a research expedition initiated by Mr. R. E. Leakey, Director of the National Museums of Kenya, in 1967 to determine the paleontologic and anthropologic potential of the area to the east of Lake Rudolf. Geologic investigation of the area was initiated by A. K. Behrensmeyer in 1969 (Leakey et al., 1970). A survey concerning the regional geology was undertaken by a team from Iowa State University in 1970 and as a result, the Upper Cenozoic sedimentary sequence has been differentiated and preliminary interpretations of the environments of deposition and geologic history have been presented (Vondra et al., 1971; Bowen and Vondra, 1973).

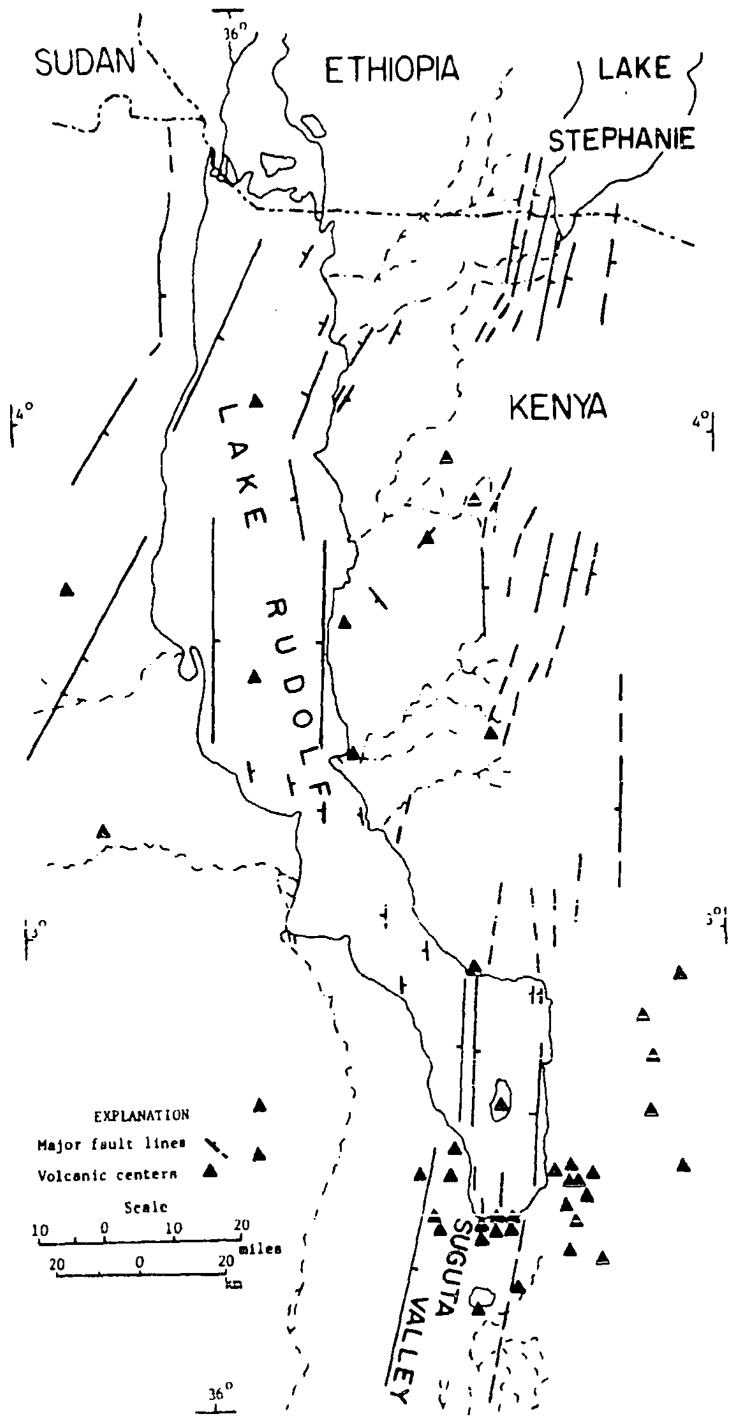
Geologic Setting

The Lake Rudolf basin is located at the northern end of the Kenya Rift System in the transitional zone between the Kenyan and Ethiopian domes. The main rift forms the Suguta Valley at the southern end of Lake Rudolf and trends across the lake in a north-northeasterly direction. The northward continuation of the trend and the zone of transition is the Kinu Sogo fault zone east of Lake Rudolf and the Stephanie graben on the Ethiopian border (Baker et al., 1972). The area of study lies on the northwestern flanks of this trend (Fig. 5).

The Suregei cuesta forms the northeastern and eastern margin of the area of study upheld by a series of westward dipping Upper Cenozoic (17.4 to 2.2 myBP; Fitch and Miller, 1974) interbedded basalt flows and associated paleosols, ignimbrites, tufts and sediments. The Miocene (11.6 ± .5 myBP) volcanics which form a basement upon which the late Cenozoic sediments were deposited were tilted westward by early Pliocene faulting and folding, forming an asymmetrical fault basin or half-graben bounded on the west by a major fracture system and on the east by a monoclinal flexure. Along the eastern and southern margins of the basin a complex of volcanics of Pliocene age is exposed down dip of the outcrop of Miocene volcanics. Lower Pliocene (7.5 ± .8 myBP; Fitch and Miller, 1974) peralkaline rhyolitic volcanic plugs occur as isolated relief features (Kubi Algi and Derati) which have been surrounded and partially buried by Upper Pliocene (3.8 ± 4 myBP; Fitch and Miller, 1974) flood basalts. The northeast-southwest trending Kokoi horst complex, to the north of Koobi Fora, is a sequence of faulted and uplifted Upper Pliocene (3.62 ± .36 myBP) basalt flows and interbedded lacustrine sediments and tufts.

Faults in the area, although numerous, are of minor importance forming small half-graben, graben and horsts with a general northward trend paralleling that of the present lake basin. Shallow echo sounder reflections provided by A. J. Hopson of the Lake Rudolf Fisheries, indicate that the present lake basin consists of a series of northward trending grabens.

Fig. 5. Outline tectonic map of the Lake Rudolf Area



Outline tectonic map of the Lake Rudolf Area

STRATIGRAPHY

The Upper Cenozoic of the northern portion of the Lake Rudolf basin consists of 325 meters of fluvial, deltaic, transitional-lacustrine and lacustrine sediments deposited disconformably on the Upper Miocene and Pliocene volcanics. The sediments occur in a band 10 to 40 kilometers wide and 80 kilometers long extending along the lake shore southward from Ethiopia. Outcrops show little relief, are discontinuous and generally mantled with terrace, beach or aeolian sand. Except for reversals due to faulting, the sediments dip gently toward the lake and off the Kokoi horst.

The sedimentary exposures were originally separated into three areas because of the difficulty of stratigraphic correlation between them (Vondra et al., 1971). The exposures at Ileret, the southernmost area, are separated from those along the Koobi Fora ridge, the central area, by the Kokoi horst structure and a large Holocene alluvial plain complex to the east of the Kokoi. The Holocene flood plain deposits of the intermittent stream, Laga Bura Hasuma separate the Kubi Algi area, the southernmost, from the Koobi Fora area. This resulted in two sets of stratigraphic terms. In the Ileret area the sedimentary sequence was divided into three unconformable units designated the lower, middle and upper units. While on the Koobi Fora - Allia Bay area the sequence was divided into four units designated as Koobi I, II, III and Galana Boi (Leakey et al., 1970; Vondra et al., 1971).

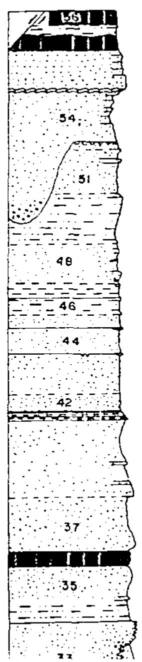
Continuous marker beds were subsequently recognized in the Upper Cenozoic sediments and were physically traced laterally from the Ileret area to the Koobi Fora and Allia Bay areas. With the correlation established, the stratigraphic nomenclature was developed and formalized (Bowen and Vondra, 1973).

Kubi Algi Formation

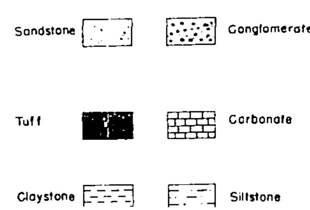
The predominantly coarse-grained Pliocene strata in the northeastern part of the Lake Rudolf basin which lie unconformably on Miocene or Pliocene volcanics or are in fault contact with the volcanics and are conformably overlain by fine-grained Plio-Pleistocene strata were named the Kubi Algi Formation (Bowen and Vondra, 1973). The Kubi Algi strata vary laterally across the basin, but retain features which give them unity for the purposes of mapping. The most unifying features of the strata are their position with respect to both older and younger rocks, the fining upward sequence from pebble conglomerates with large cut and fill structures to very fine-grained sandstones and laminated claystones, and the high percentage of volcanic rock fragments contained in the coarse sediments. The base of a complex of laminated bentonitic tuffs and claystones, named the Suregei Tuff Complex (Bowen and Vondra, 1973), marks the upper boundary of the Kubi Algi Formation. The type locality was designated as the center (3°45' N latitude and 36°19' E longitude) of a tranverse taken along a terrace trending toward Kubi Algi, a prominent butte located 20 kilometers east of Allia Bay (Fig. 6). The type section consists of a composite of the strata exposed in low lying outcrops along the terrace from a point 4 kilometers south of Kubi Algi toward the Laga Bura Hasuma 4 kilometers N 50° E of Allia Bay. Three other exposures of the Kubi Algi were measured and described

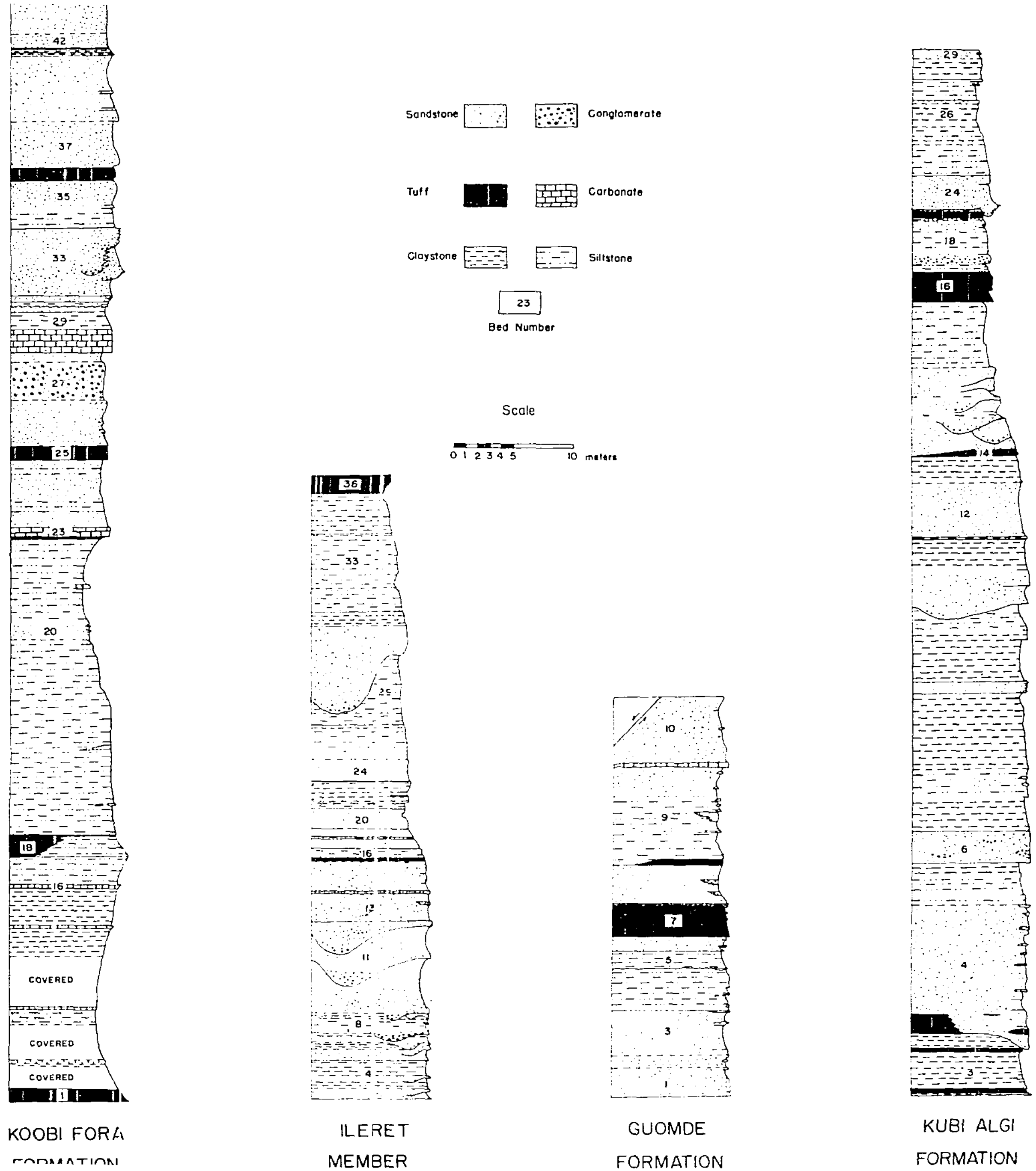
Fig. 6. Type sections of the Upper Cenozoic sediments, East Rudolf, Kenya

TYPE SECTIONS OF THE UPPER CENOZOIC SEDIMENTS, EAST RUDOLF, KENYA



EXPLANATION





Sandstone
Conglomerate
Tuff
Carbonate
Claystone
Siltstone
23
Bed Number
Scale
0 1 2 3 4 5 10 meters
COVERED
KOOBI FORA FORMATION
ILERET MEMBER
GUOMDE FORMATION
KUBI ALGI FORMATION

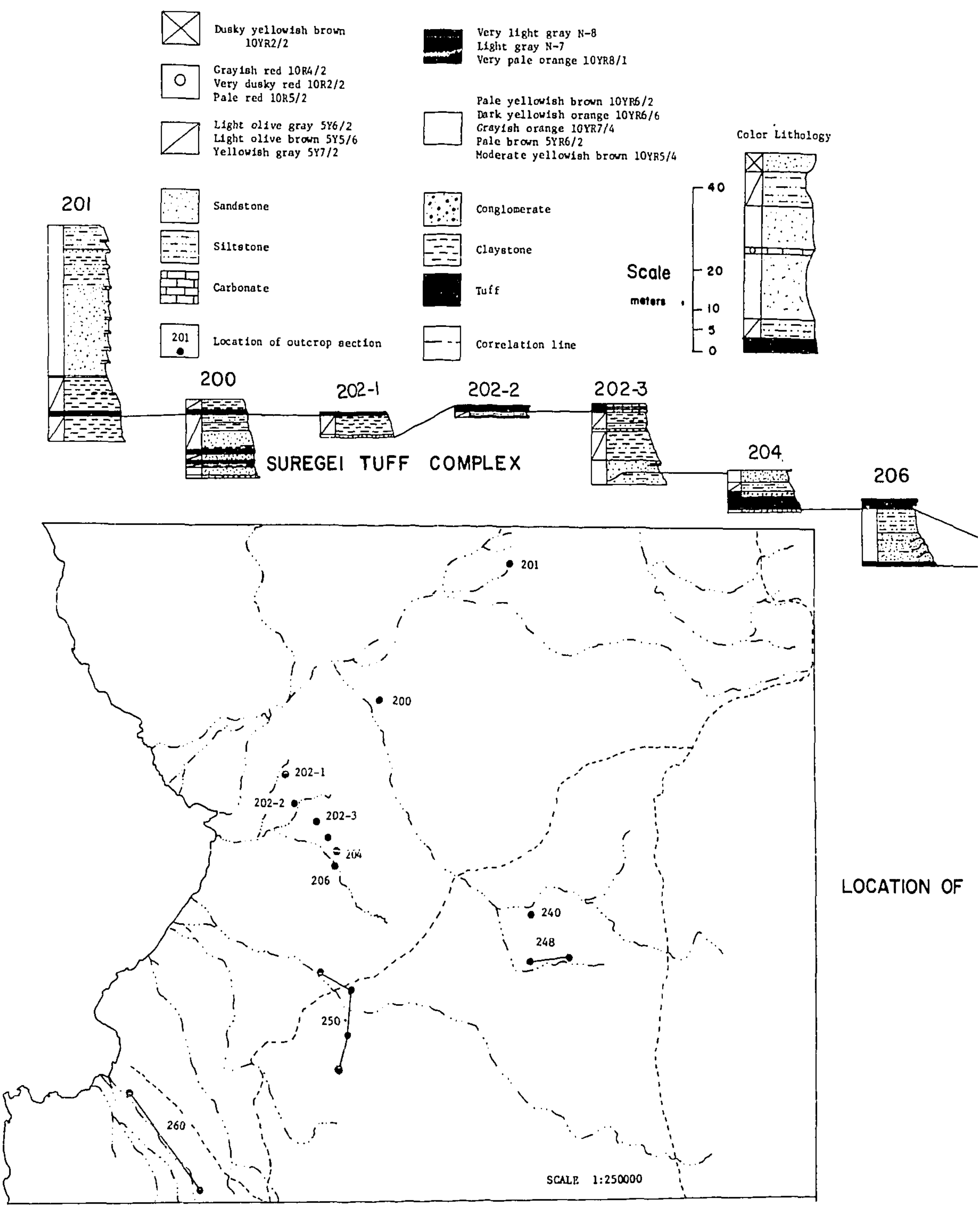
to better ascertain the lateral variations of the formation (Fig. 7). The correlations between these sections are firm except for the southernmost sequence (Fig. 7). The area between Sibilot and Jarigole is covered and no units could be traced into the Jarigole area. Thus a provisional correlation on the basis of sequence and numbers of tuffs is presented. The Kubi Algi crops out extensively in the area south of Laga Bura Hasuma and west of Kubi Algi to the southern margin of the northeastern part of the Lake Rudolf basin. North of Laga Bura Hasuma exposures of the Kubi Algi Formation are limited to the western margin of the Suregei cuesta and a small area between the Kokoi horst and the Koobi Fora ridge. The Kubi Algi Formation as proposed by Bowen and Vondra (1973) is equivalent to the lower portion of the informal Koobi Fora I (Vondra et al., 1971).

At its type locality the Kubi Algi Formation consists of a series of light colored (pale yellow brown, 10YR6/2) basalt cobble conglomerates and conglomeratic sublitharenites, dark colored (dark yellowish brown, 10YR4/2) fine-grained sublitharenites, drab siltstones and claystones (light olive gray 5Y6/1, pale yellowish brown, 10YR6/2 and yellowish gray 5Y7/2) and light gray (N-7) to pale yellowish brown, (10YR 7/2) fine-grained tuffs (Fig. 8). The sandstones fine upward from coarse to fine-grained and tend to decrease in color value upward from 10YR6/2 to 10YR4/2. Bedding of the sandstones also decreases in magnitude vertically from large-scale trough cross-beds to ripple-laminations and eventually parallel laminations. Units for the most part are lenticular and relatively thick averaging 3.5 meters. Near the top they become noticeably thinner averaging 1.7 meters. The units grade or interfinger

Fig. 7. Graphic sections of the Upper Cenozoic sediments, Allia Bay, East Rudolf

GRAPHIC SECTIONS OF THE ALLIA BAY,

EXPLANATION



LOCATION OF

GRAPHIC SECTIONS OF THE UPPER CENOZOIC SEDIMENTS,

ALLIA BAY, EAST RUDOLF

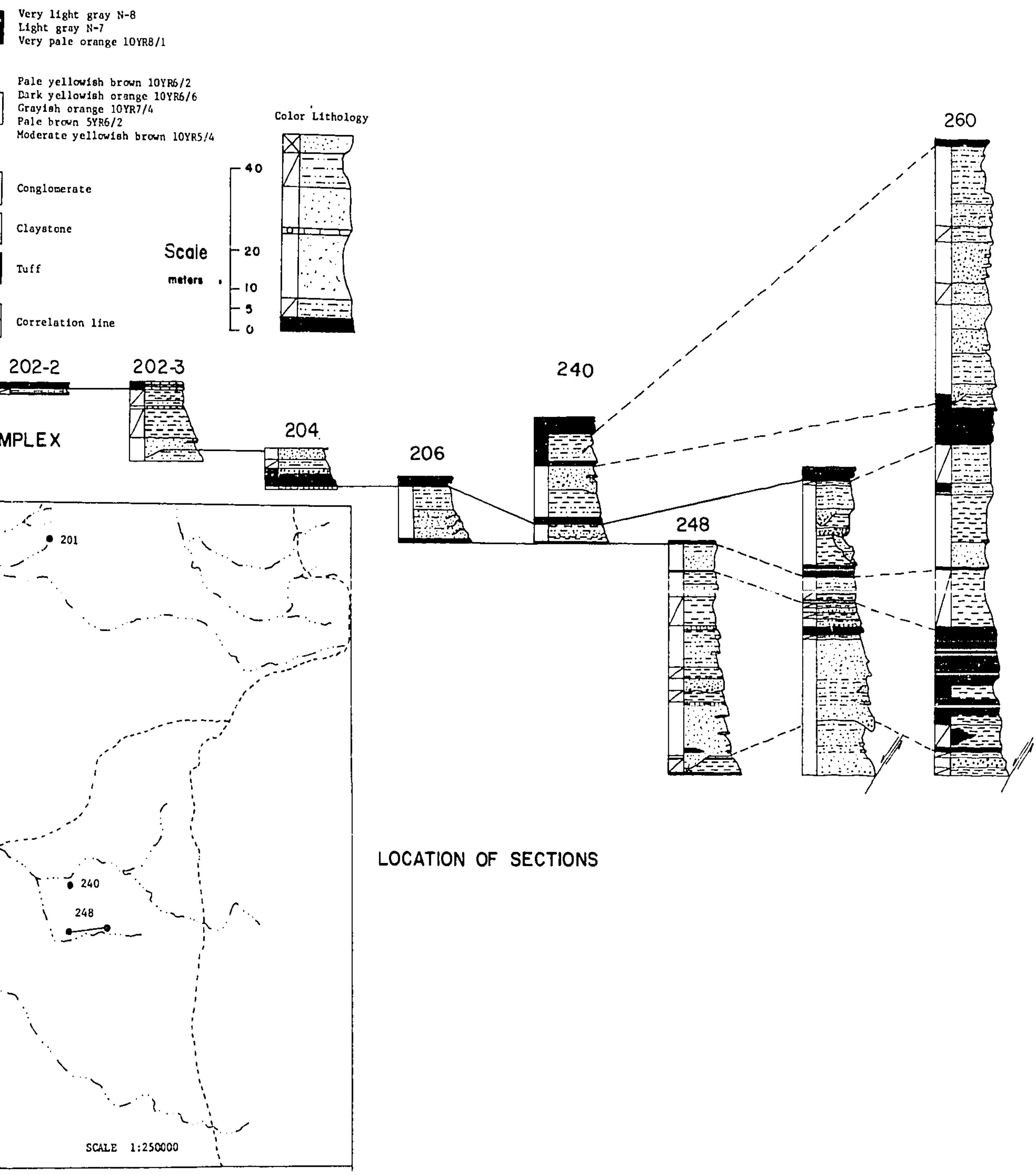


Fig. 8. Photographs of the Kubi Algi Formation

a. Laminated siltstones and Suregei Tuff Complex near Derati

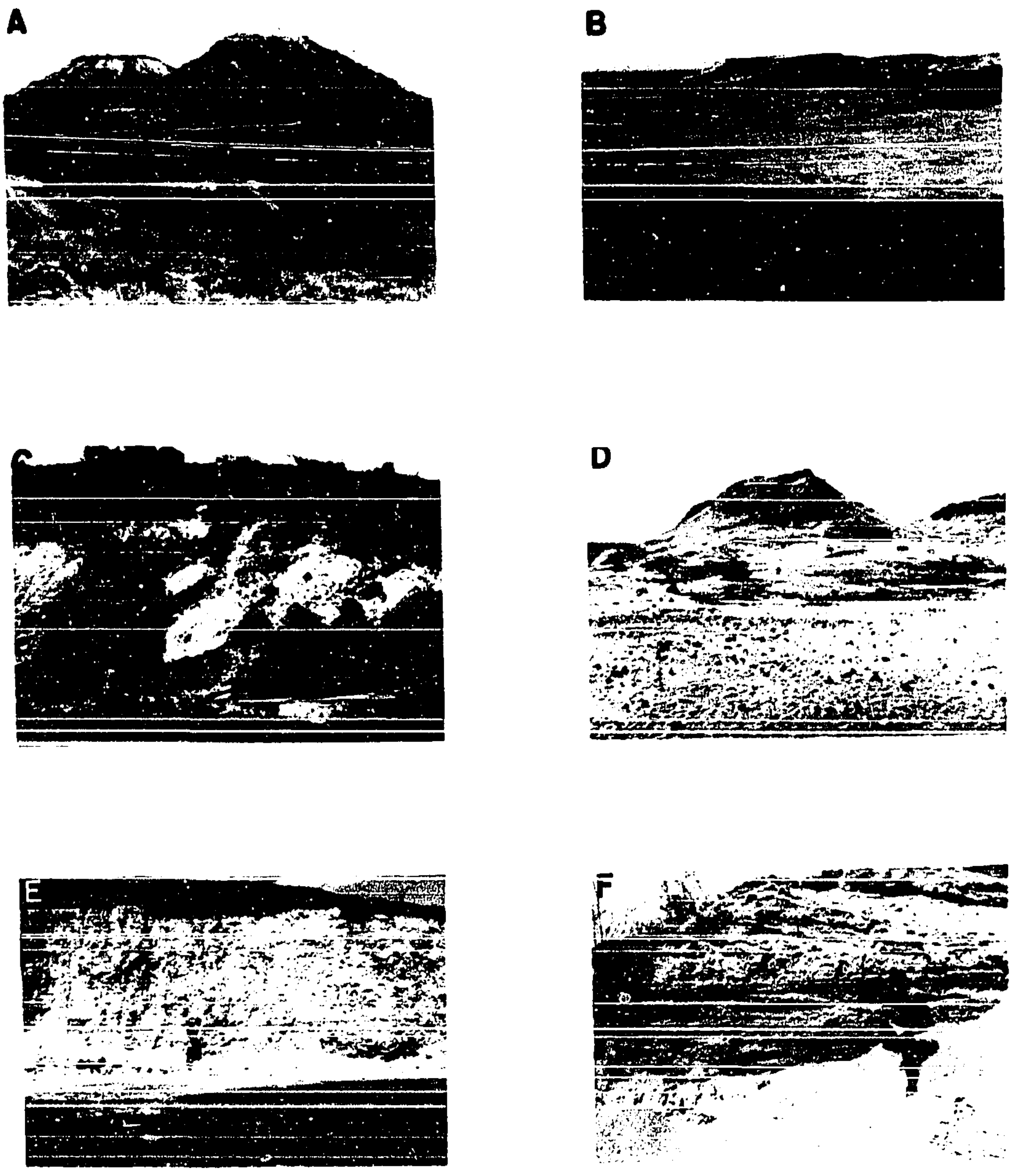
b. Kubi Algi Formation is in fault contact with Sibilot, a flat top mesa composed of ignimbrites

c. Typical exposure of Kubi Algi Formation along a terrace

d. Derati, a peralkaline rhyolitic plug, is a prominent feature along the margin of the basin in the Allia Bay Area

e. Tuff units tend to thicken southwest of Sibilot

f. Exposure of conglomerates in lower portion of Kubi Algi Formation



laterally with each other. Vertically there are few gradational contacts, making the units easily separable.

Fossils are relatively rare in the Kubi Algi Formation. There are ostracods in a tuff near the base at the type locality and gastropods and pelecypods in two thin sandstones at the top. Abraded vertebrate fossils are scattered throughout the sequence but are only rarely encountered. Trace fossils, such as sand-filled root casts, are present in most of the siltstones and in some of the claystones and sandstones. A thickness of 98 meters is attained by the formation at its type locality.

The Kubi Algi Formation exhibits a considerable degree of lateral variation. Southward the sequence thickens from 98 meters at the type locality to 153 meters near Jarigole (Fig. 7). The upper portion of the formation, measured from a key tuff horizon, thickens from 32 meters near Kubi Algi to 100 meters near Jarigole. Thus the lower portion of the formation is of about equal thickness from north to south.

The lithologies of the coarse clastics vary from north to south as well. At the type locality cobble to pebble-sized basalt fragments are the dominant constituent of the conglomerates. Northward there is a sizeable contribution to the conglomerates from the rhyolitic plugs of Derati and Kubi Algi. Toward Jarigole the conglomerates consist of ignimbrite cobbles and pebbles.

The average particle size and the volume of coarse-grained units tend to increase toward Jarigole. Ignimbrite pebble and cobble conglomerates and very coarse-grained litharenites dominate the sequence.

Unlike the type section, the units in the south are arranged into four fining upward cycles with conglomerates at the base and siltstones at the top of each. Tuffs increase in thickness southward but the particle-size tends to decrease.

Fossils are even more scarce toward Jarigole. Gastropods and ostracods occur in a bioclastic carbonate unit in the middle of the second fining upward sequence. Vertebrate fossils were found only at the base of the sequence near Sibilot. Root casts occur throughout the sequence (Fig. 8).

Type Section of the Kubi Algi Formation

Allia Bay

Lake Rudolf, Kenya

This section was measured from 4 km south of Kubi Algi $3^{o}44'$ N latitude, $36^{o}26'$ E longitude along a terrace trending N 60^{o} W to Laga Bura Hasuma, $3^{o}48'$ N latitude $36^{o}18'$ E longitude.

Bed	Description	Thickness (meters)
	Pliocene Series Kubi Algi Formation Total thickness 98.0 m	
29	Sublitharenite; dark yellowish brown, 10YR4/2; fine grading to very fine-grained; subrounded, well sorted grading to very poorly sorted; composed of detrital quartz, feldspar, rock fragments, mica; locally calcareous or ferruginous, argillaceous at the top; basal contact is distinct; small-scale cross-beds are present; contains slightly abraded gastropods and pelecypods in middle resistant unit; loose and generally nonresistant........................	0.7

Bed	Description	Thickness (meters)
28	Siltstone vertically grading to claystone; yellowish gray, 5Y7/2; tuffaceous at base, slightly silty toward top and limonitic throughout; basal contact is sharp; limonitic silt filled, root casts and limonite concretions occur throughout; interbeds of sublitharenite, grade laterally to well indurated limonitic fine grained sublitharenite; the unit is blocky, saline, selenite crystals occur in fractions, the unit is friable and deeply weathered..........	3.9
27	Sublitharenite; dark yellowish orange, 10YR 6/6; composed of very fine-grained, well rounded, very poorly stored, quartz grains and rock fragments; the unit is argillaceous basal contact is sharp; the unit is capped by 15 cm layer of selenite; it is parallel laminated; friable but resistant..............	0.4
26	Claystone; light olive gray, 5Y5/2 grades to yellowish gray, 5Y6/2; local occurrences of hematite, selenite occurs in joints, saline throughout; basal contact is gradual transition rapid limonitic silt-filled root casts occur throughout, limonite concretions occur along bedding planes; parallel laminated with fine laminae predominating; dendritic, well indurated, but deeply weathered....................................	3.2
25	Siltstone; yellowish gray, 5Y5/7 grades to grayish orange, 10YR7/4; sandy in the middle to argillaceous and tuffaceous at top; basal contact is very sharp; lenticular-bedded with sand lenses less than .5 cm thick occur throughout, fine material predominating; limonitic root casts; unit breaks into large blocks; well indurated and deeply weathered....................................	3.4
24	Sublitharenite; grayish orange, 10YR7/4; consists of medium-grained, spherical and subrounded, well sorted, grains of quartz, rock fragments, orthoclase, hornblende, mica; calcareous at the top and limonitic throughout; basal contact is very sharp and	

Bed	Description	Thickness (meters)
	erosional; very indistinct low angle small-scale planar cross-beds heading S 10° E; calcareous root casts occur throughout, 2 m long pipe-like concretions occur in the middle, loose to well indurated and resistant................	3.0
	Traced laterally to continue section Laterally this sublitharenite becomes very fine-grained, well rounded, well sorted, basal contact distinct, low angle small-scale planar cross beds, horizontal sand-filled burrows, mammalian fossils, fish and gastropods at top.	
23	Siltstone; light olive gray, 5Y5/2, as unit 19 below....................................	0.3
22	Tuff; pale yellowish brown, 10YR7/2; composed of fine silt-sized glass shards; basal contact is distinct; unit is thin bedded with fine layers predominating, contains calcareous root casts, selenite in joints; unit is well indurated but nonresistant.....................	0.4
21	Siltstone; light olive gray, 5Y5/2, as unit 19 below....................................	0.3
20	Sublitharenite; dark yellowish gray, 5Y6/2; consists of medium to coarse-grained, subangular to subround, poorly sorted grains of of quartz, rock fragments, clay galls; slightly calcareous; basal contact is gradual transition slow; Kappa type 1 ripple-laminated are present; mammalian fossils occur throughout friable but nonresistant......................	0.7
19	Siltstone; yellowish gray, 5Y7/2; very sandy; basal contact is gradual transition slow; lenticular-bedded; limonitic root casts are numerous, calcareous concretions occur throughout; very blocky, well indurated but nonresistant.................................	2.4
18	Conglomerate; grayish orange, 10YR7/4 grades to pale yellowish brown, 10YR6/2 and back to grayish orange, 10YR7/4; consists of granule to pebble-sized particles which grade to medium to fine-grained litharenite; grains	

Bed	Description	Thickness (meters)
	are well rounded and very poorly sorted; composed of basalt, sandstone and siltstone fragments; parallel bedding with coarse material predominating, thin silt beds between coarse material; moderately well indurated and resistant........................	1.5
17	Siltstone; pale brown, 5YR5/2; slightly sandy; basal contact is distinct; lenticular-bedded; numerous calcareous root casts occur throughout, slickensided "peds" are common, probably weathering horizon; dendritic, well indurated and moderately resistant..........................	1.6
16	Tuff, grayish yellow, 5Y8/4 to light gray, N-7 to very pale orange, 10YR8/2 at top; consists of medium silt-size glass shards, slightly sandy to slightly argillaceous; basal contact is very sharp; Kappa Type 1 ripple-laminations to parallel laminated occur laterally, center section break into large 15 cm - 25 cm blocks, few root casts occur, friable but resistant.................. Traced laterally to continue section	1.5-2.8
15	Sublitharenites; grayish orange, 10YR7/4 interbedded with siltstones, pale brown, 5YR5/2; composed of very coarse to clay-size particles; sands are well rounded and poorly sorted consisting of quartz, rock fragments mica; calcareous; basal contact is very sharp; contains low angle small-scale planar cross-beds; mammalian fossils, calcareous root casts and calcareous concretions are common; probably channel, levee and proximal flood basin at end of distributary system, lenticular-bedded silts, concretionary weathering, sand-iron oxide and sand-calcite concretions on surface, well indurated and resistant..........	13.5
14	Tuff; light gray, N-7; consists of very coarse silt-sized grains and pumice granules to pebbles up to 2 cm in diameter; basal contact is gradual transition slow; contains low angle small-scale planar cross	

Bed	Description	Thickness (meters)
	beds with one component dipping heading west; calcareous root casts and concretions occur at base, deeply weathered................	0.6
	Faulted out by Kubi Algi, tuff traced through isolated outcrops to terrace west of Kubi Algi	
13	Claystone; very pale brown, 10YR6/2, as unit 11 below.....................................	2.6
12	Sublitharenite; grayish orange, 10YR7/4 as unit 10 below.................................	5.1
11	Claystone; very pale brown, 10YR6/2; slightly silty; basal contact is gradual transition slow; contains 4 cm thick tuff lense at top; calcareous root casts and concretions are common; blocky, well indurated but non-resistant......................................	3.0
10	Sublitharenite; grayish orange, 10YR7/4; consists of fine-grained, spherical subrounded, very poorly sorted grains of quartz, rock fragments, mica; unit is argillaceous; basal contact is very sharp and erosional; contains grouped, large-scale, erosional, trough, homogenous, Pi cross-beds; fore-sets are 6 cm long; line of flow and pointing distinct - North to South; calcareous root casts and concretions occur, moderately well indurated and moderately resistant........	3.2
9	Claystone; yellowish gray, 5Y7/2 grades to siltstone, pale yellow brown, 10YR6/2; selenite occurs in joints, saline throughout; basal contact is very sharp; massive to lenticular-bedded; contains calcareous root casts and concretions; blocky, well indurated but nonresistant....................	7.1
8	Sublitharenite; grayish orange, 10YR7/4; unit is very fine-grained, argillaceous, very poorly sorted and consists of rock fragments, quartz, mica; basal contact is gradual transition slow; thin bedded, some sand lenses show ripple-lamination; well indurated and resistant................................	1.1

Bed	Description	Thickness (meters)
7	Claystone; yellowish gray 5Y7/2; siltstone, pale yellow brown, 10YR6/2; claystone, pale yellow brown, 10YR6/2; slightly sandy and tuffaceous at top; basal contact is very sharp; siltstone is lenticular-bedded; calcareous root casts and concretions are common; tuff lenses occur at top, ripple-laminated sand-lenses occur in silts; claystones are blocky, well indurated but non-resistant....................................	12.6
6	Litharenite; very pale orange, 10YR8/1; feldspathic litharenite, very fine-grained with lenses of basalt pebble conglomerates, grains are well rounded, spherical, bi-modality sorted; grains consist of quartz, rock fragments, feldspar; very argillaceous basal contact is very sharp; large-scale Omikron grades to small-scale Alpha cross-beds; low angle; calcareous root casts are common; well indurated and resistant...........	3.0
5	Siltstone; pale yellow brown, 10YR6/2 grades to claystone, grayish yellow, 5Y7/2; unit is argillaceous and sandy and grades to slightly silty; basal contact is distinct; lenticular-bedded; calcareous root casts and concretions are numerous at top; blocky, well indurated and moderately resistant........	4.0
4	Sublitharenite; pale yellow brown, 10YR6/2, grades to very pale orange, 10YR8/2, unit is very fine-grained and argillaceous at base grades to very coarse with conglomerate lenses at top; consists of subround, spherical, moderately sorted grains of quartz, rock fragments, clay, tuff, pumice, glass shards; unit is calcareous; basal contact is very sharp and down cutting; basal unit has Kappa Type 1 ripple-lamination; calcareous root casts and concretions, vertebrate fossils occur throughout loose but moderately resistant, goes laterally to tuff with sand and pumice lenses..............................	12.0
3	Interbedded claystones, light olive gray 5Y6/1 to moderate yellowish brown 10YR4/2, and tuffs, very pale orange, 10YR8/1; 3	

Bed	Description	Thickness (meters)
	claystone units are 0.15, 3.2 and 0.5 m thick and 3 tuffs are 0.5, 0.1 and and 1.0 m thick; unit starts with claystone and ends with tuff; claystones are tuffaceous and siltstones are argillaceous and coarse silt-size; basal contact is very sharp; medium bedded to parallel laminated; iron oxide concretions and selenite occur on bedding planes; ostracods occur in upper tuff; well indurated but nonresistant................	5.5
2	Claystone; dark yellowish orange, 10YR 6/6; basal contact is gradual transition slow; weathered basalt; slightly calcareous; calcareous concretions occur throughout; crumbly, very friable and nonresistant.........	.05
1	Basalt; grayish black, N-2; very fine-grained, contains gas vacuoles with glass filling; consists of olivine, plagioclase, pyroxene; unit is well jointed, highly fractured; well indurated and resistant	

Koobi Fora Formation

The sedimentary strata which lie between the basal contact of the Suregei Tuff Complex and the upper contact of the prominent Chari Tuff exposed along the Ileret ridge, or the basal contact of the Holocene, gray, diatomaceous, predominantly lacustrine siltstones were named the Koobi Fora Formation (Bowen and Vondra, 1973). The exposures located east of Koobi Fora spit at 3°56' N latitude and 36°15' E longitude (HBH 6136, East Africa Grid) best illustrate the lithology of the formation and were designated as the type locality (Bowen and Vondra, 1973) (Fig. 6). The unit as defined includes the upper portion of the informal Koobi Fora I and the Koobi Fora II and III units of Behrensmeyer (Leakey et al., 1970) and Vondra et al. (1971). The formation outcrops throughout the East Rudolf embayment of the Lake Rudolf basin north of Derati and the mouth of the Laga Bura Hasuma.

The Koobi Fora Formation is a heterogeneous sequence of boulder to granule-sized conglomerates, coarse to fine-grained sandstones, variegated siltstones and claystones, bioclastic carbonates and sedimentary tuff horizons. It varies in thickness from 135 meters along the Karari escarpment near the basin margin to 175 meters near the Koobi Fora spit and from 210 meters at Ileret to 47 meters near Derati (Figs. 9 and 10). Since all of the units are highly lenticular and grade vertically and grade or interfinger with each other laterally, the tuffs proved to be the best marker horizons. The character of the tuffs, the sequence of tuffs and the vertical separation of successive tuffs proved to be the most useful in correlating the discontinuous, low lying exposures across the basin (Fig. 11) and for subdividing the formation into members.

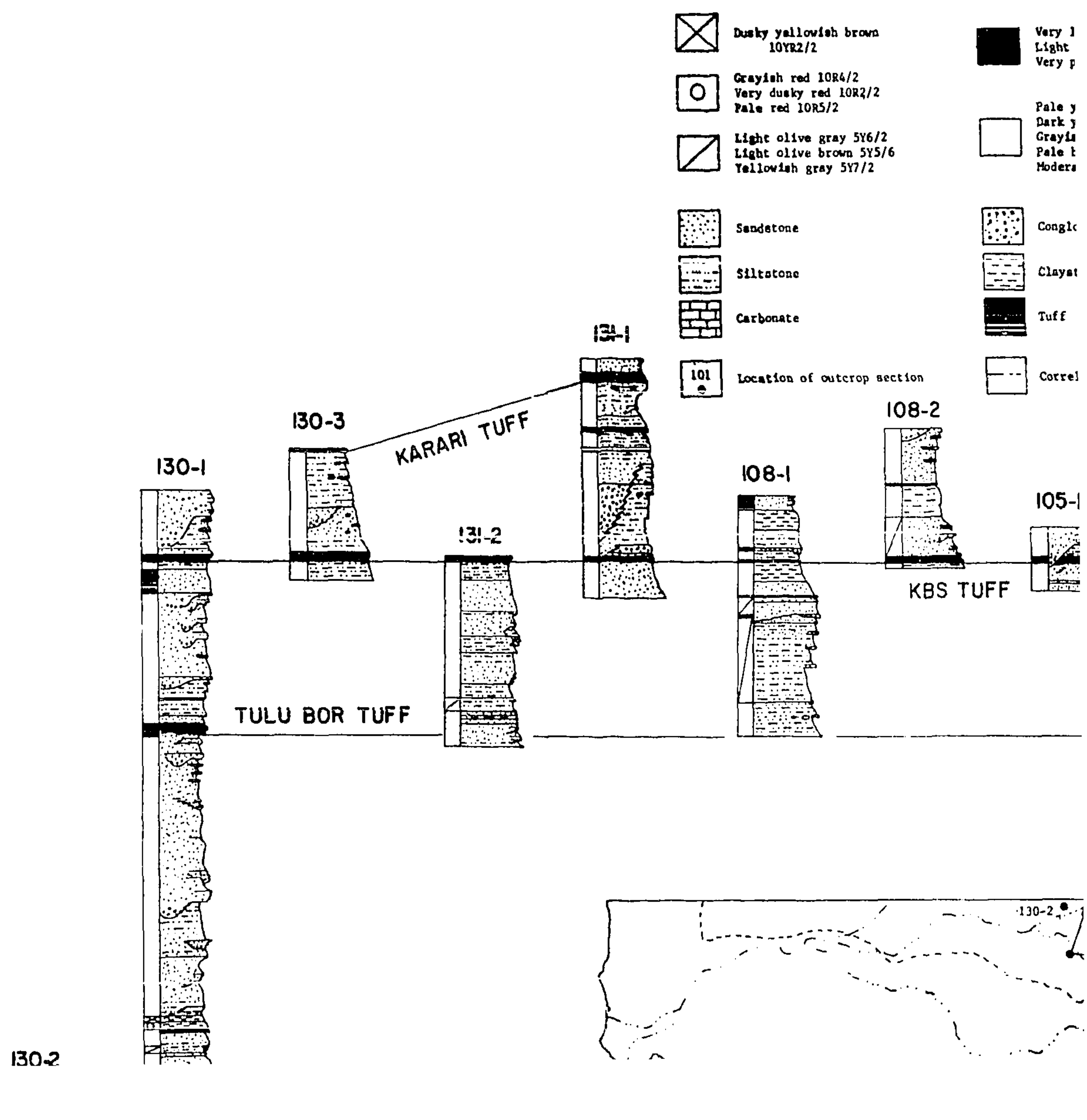
Although there are several tuff horizons in the Koobi Fora Formation, only a few are useful for correlation purposes and thus were given names (Bowen and Vondra, 1973). The Suregei Tuff Complex at the base of the Koobi Fora Formation which outcrops more or less continuously along the western margin of the Suregei cuesta, was used to establish a correlation between the Ileret and Koobi Fora areas. The unique characteristics of thin parallel laminated sequences of interbedded tuffs and claystones allowed the Suregei Tuff Complex to be identified at the type locality as well as to the south of Laga Bura Hasuma (Fig. 11a).

The Tulu Bor Tuff outcrops extensively between the Laga Tulu Bor

Fig. 9. Graphic sections of the Upper Cenozoic sediments, Koobi Fora, East Rudolf

GRAPHIC SECTIONS

EXPLANATION



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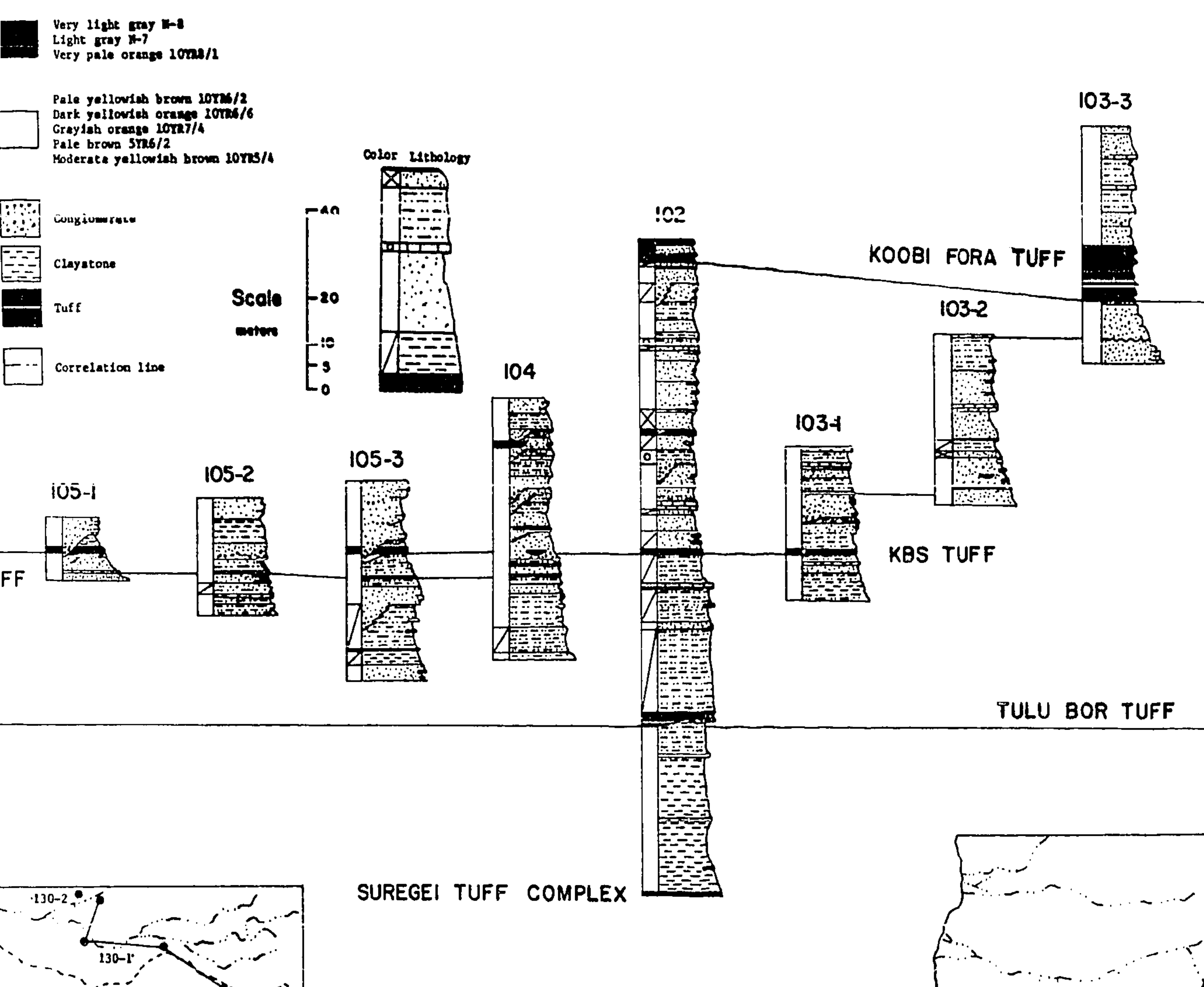
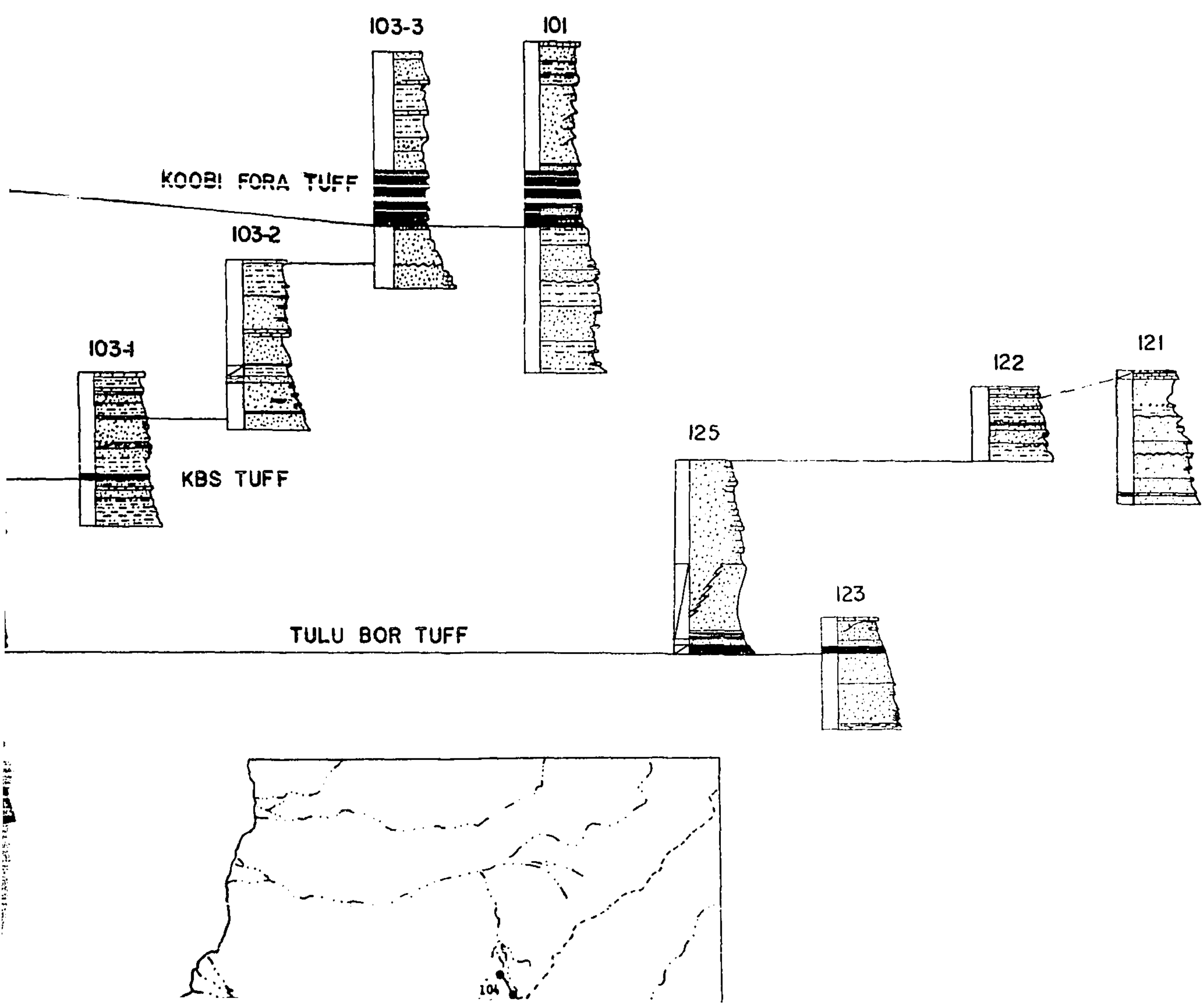
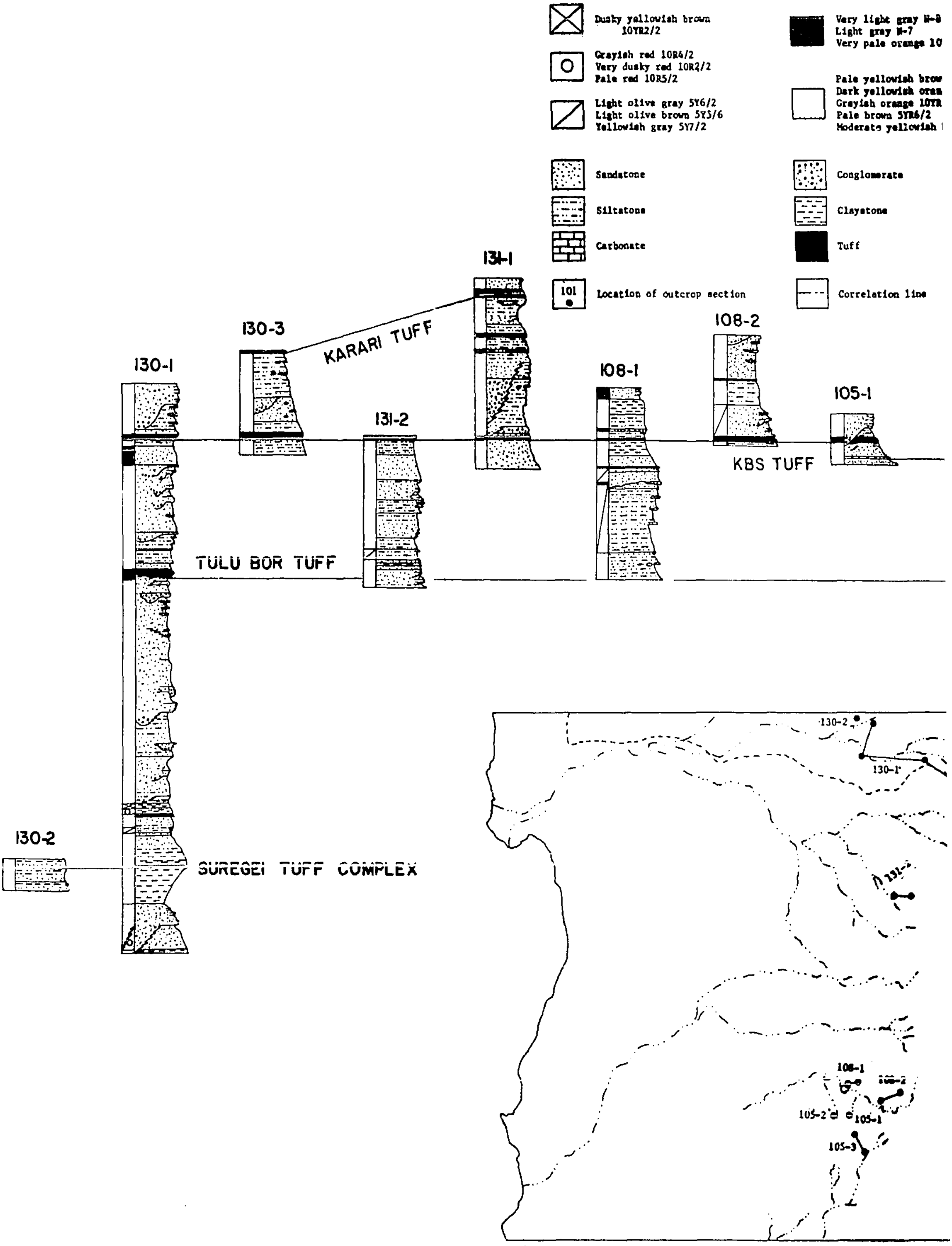
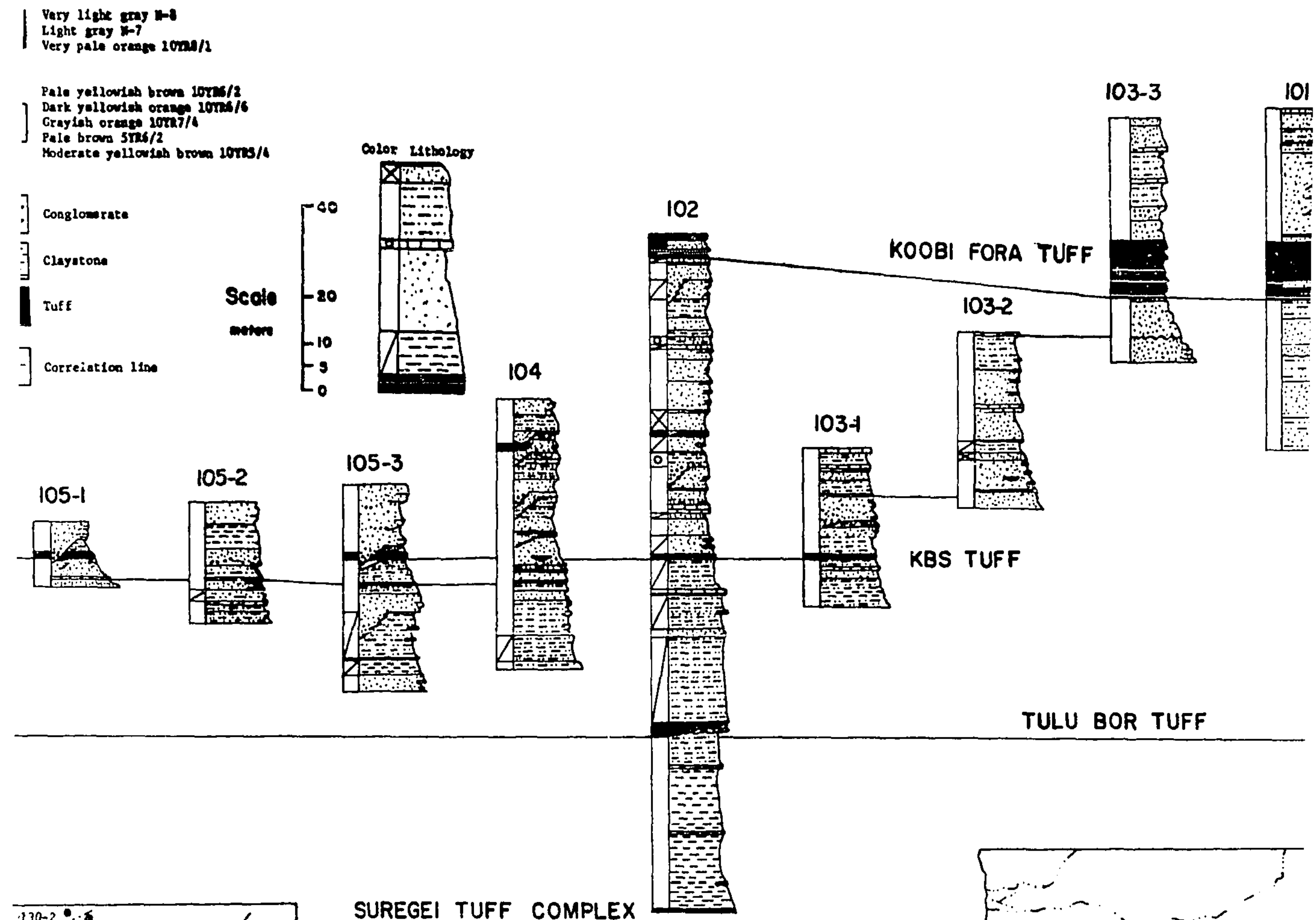


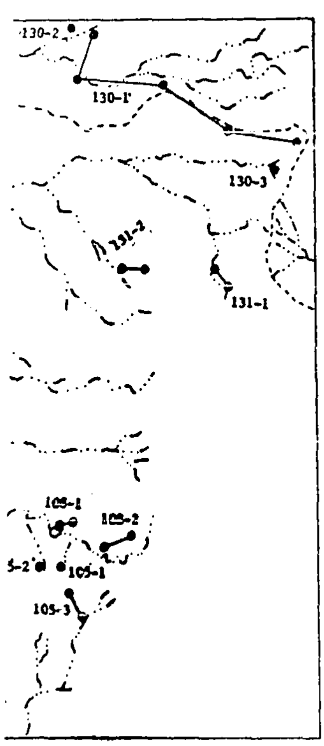
ENTS, KOOBI FORA, EAST RUDOLF





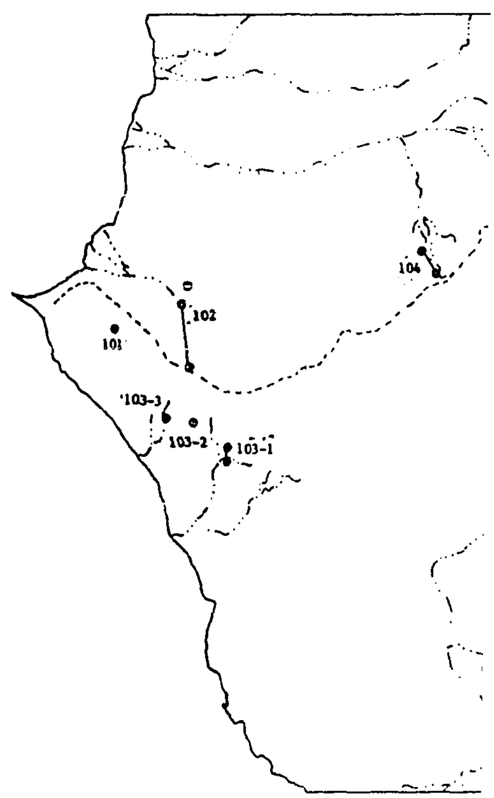
Dusky yellowish brown 10YR2/2
Grayish red 10R4/2
Very dusky red 10R2/2
Pale red 10R5/2
Light olive gray 5Y6/2
Light olive brown 5Y5/6
Yellowish gray 5Y7/2
Very light gray N-8
Light gray N-7
Very pale orange 10
Pale yellowish brow
Dark yellowish oran
Grayish orange 10YR
Pale brown 5YR6/2
Moderate yellowish
Sandstone
Siltstone
Carbonate
Conglomerate
Claystone
Tuff
101
Location of outcrop section
Correlation line
130-1
130-2
130-3
131-2
131-1
108-1
108-2
105-1
KARARI TUFF
KBS TUFF
TULU BOR TUFF
SUREGEI TUFF COMPLEX
105-2
105-3

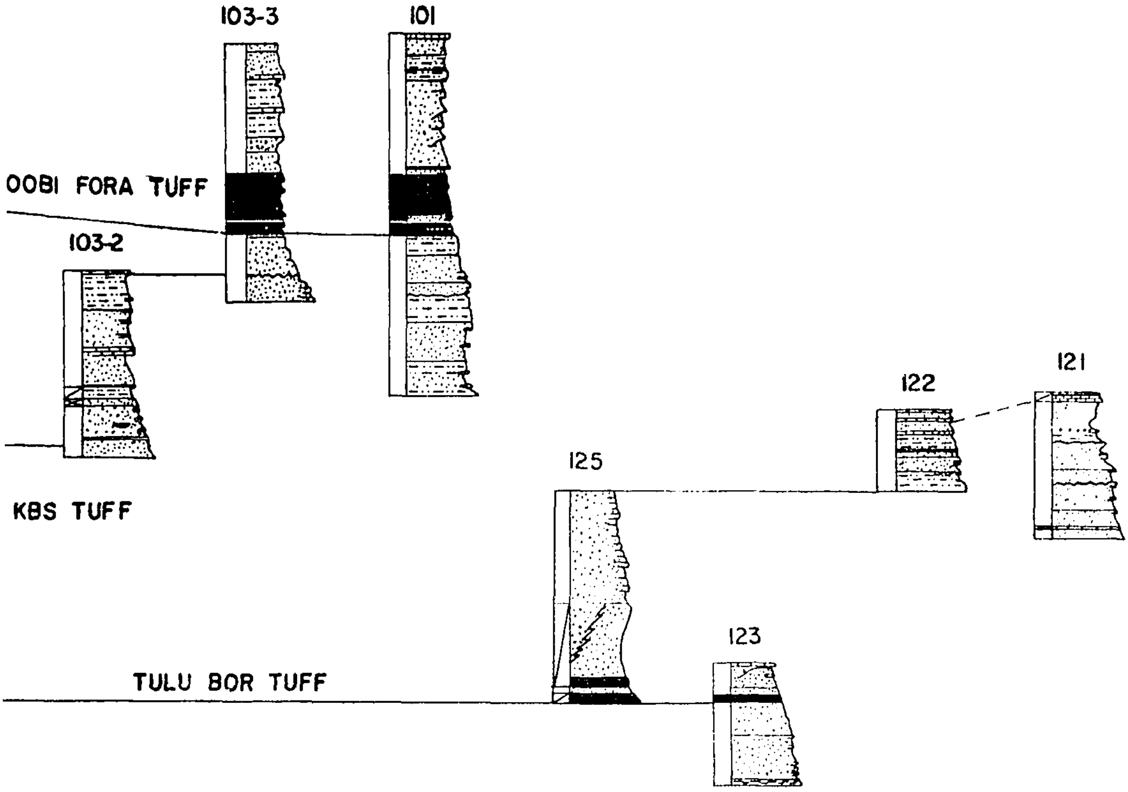




LOCATION OF SECTIONS

SCALE 1:250000




103-3
101
OOBI FORA TUFF
103-2
122
121
125
KBS TUFF
123
TULU BOR TUFF

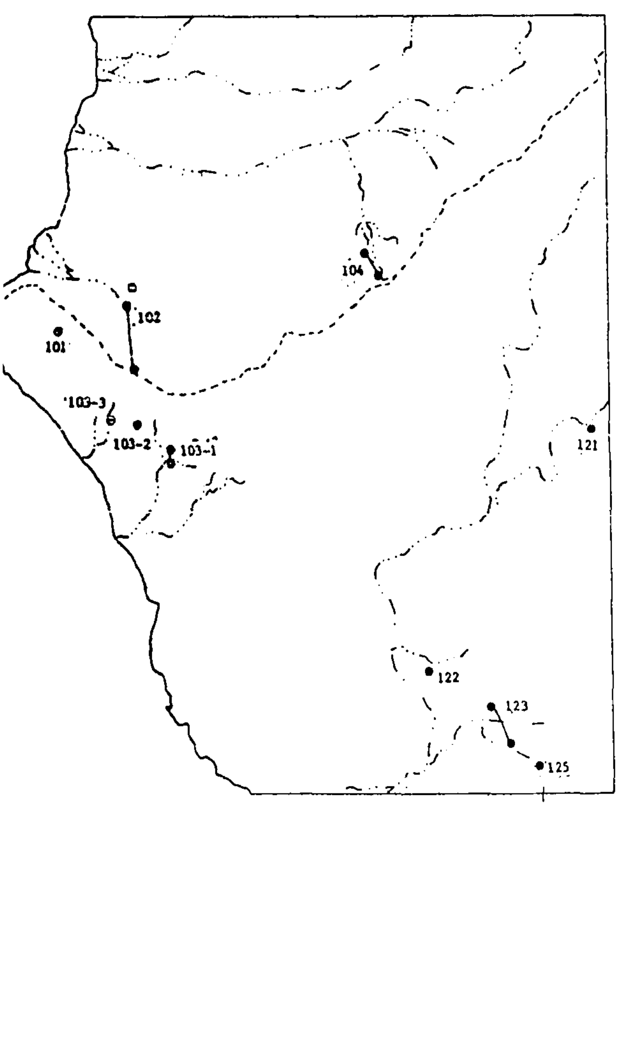
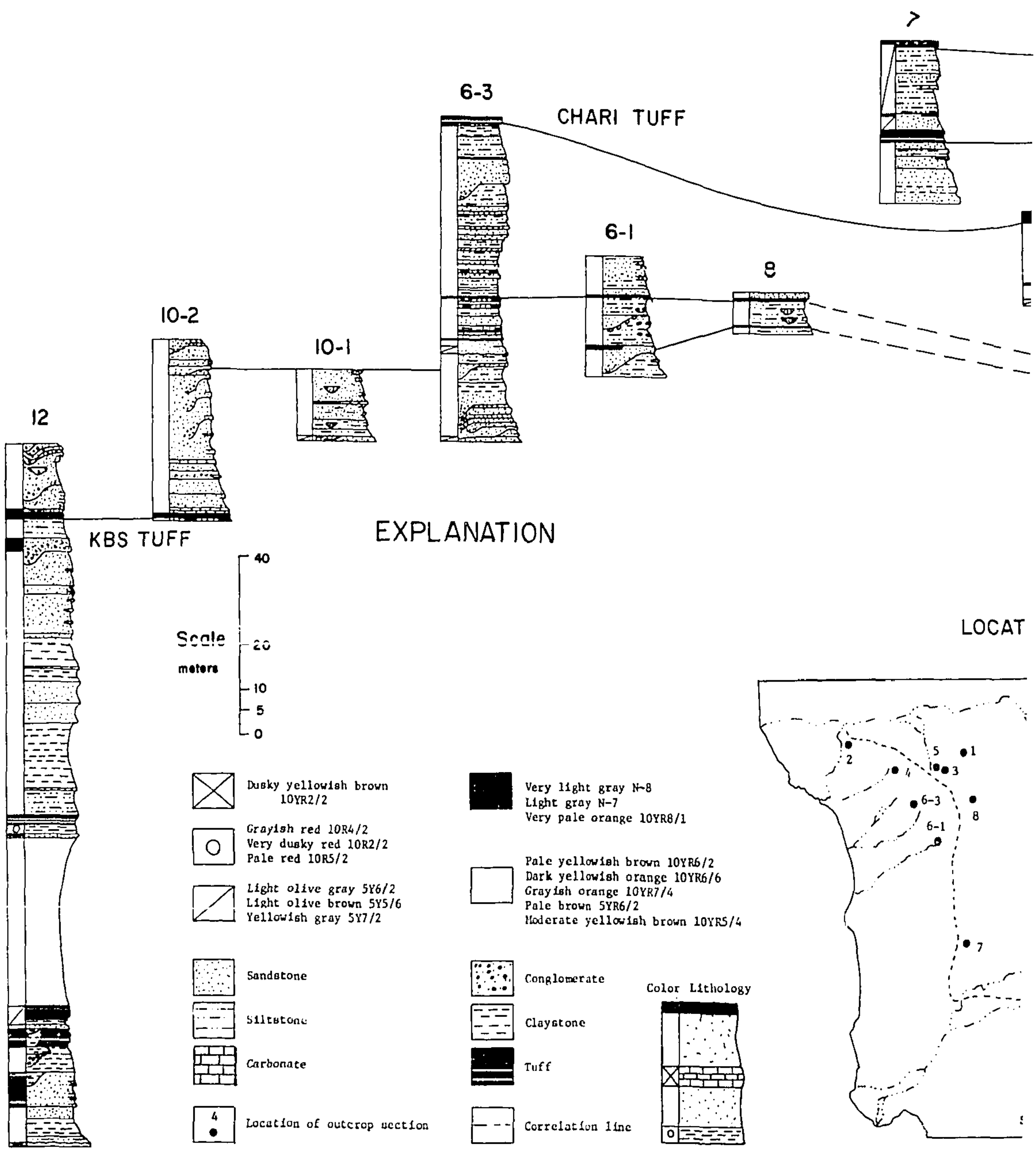

104
102
101
103-3
103-2
103-1
121
122
123
125

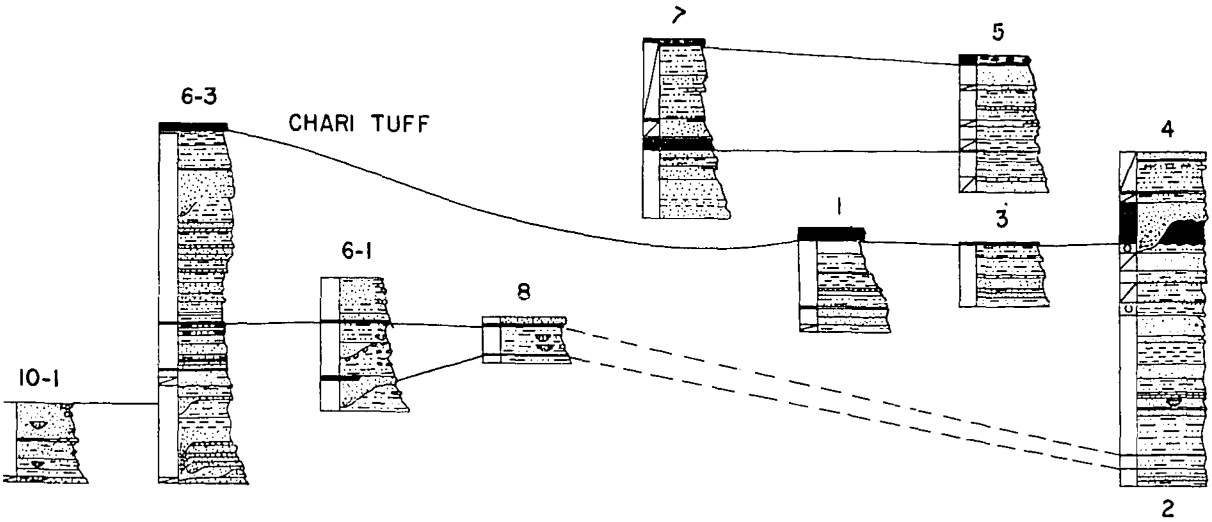
Fig. 10. Graphic sections of the Upper Cenozoic sediments, Ileret, East Rudolf

GRAPHIC SECTIONS OF THE UPPER CENOZOIC SEDIMENTS, ILERET, EAST RUDOLF



IS OF THE UPPER CENOZOIC

ET, EAST RUDOLF



EXPLANATION

ellowish brown
YR2/2

red 10R4/2
sky red 10R2/2
1 10R5/2

live gray 5Y6/2
live brown 5Y5/6
sh gray 5Y7/2

ne

ne

te

n of outcrop section

Very light gray N-8
Light gray N-7
Very pale orange 10YR8/1

Pale yellowish brown 10YR6/2
Dark yellowish orange 10YR6/6
Grayish orange 10YR7/4
Pale brown 5YR6/2
Moderate yellowish brown 10YR5/4

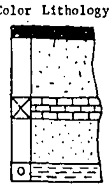
Conglomerate

Claystone

Tuff

Correlation line

Color Lithology



LOCATION OF SECTIONS

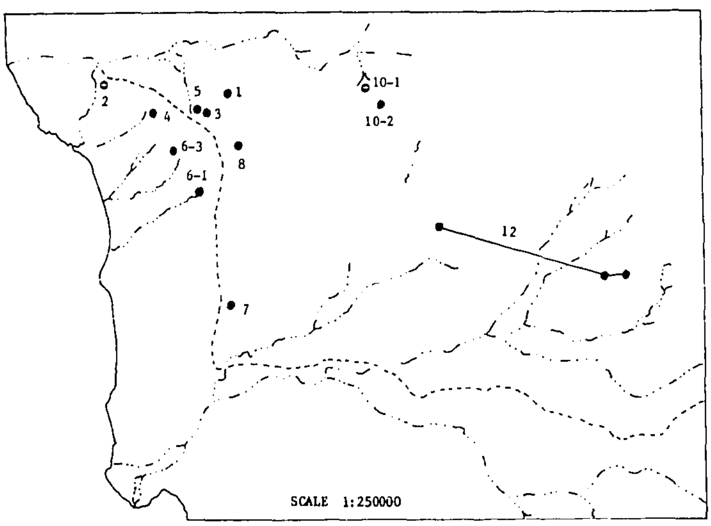


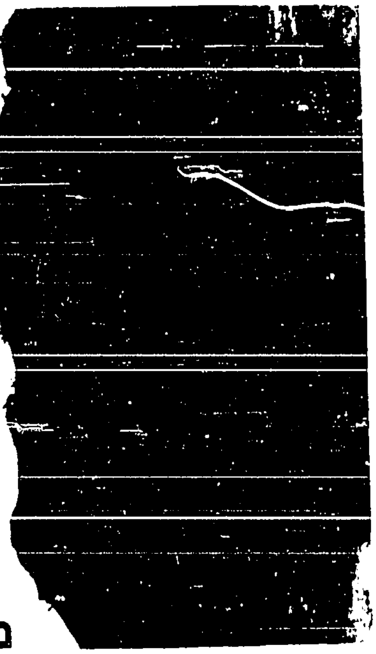
Fig. 11. Photographs of the lower tuffs of the Koobi Fora Formation

a. Suregei Tuff Complex near the Suregei cuesta showing typical exposure

b. KBS Tuff along the Karari escarpment

c. Tulu Bor Tuff along Laga Tulu Bor showing cross-bedding

B



A

C

and the southern margin of the Kokoi. There it has been displaced by the numerous faults which form the Kokoi horst complex. It can only be identified by its characteristic appearance along the eastern margin of the basin in the Ileret area, along the southern margin of the Kokoi, between the Kokoi and the Koobi Fora ridge, at the type locality and near the mouth of the Laga Bura Hasuma. The tuff consists of two separate and distinct units, the lower unit is fine-grained and parallel laminated while the upper unit contains calcareous concretions and lenses of pumice pebbles and sand. Locally it is trough cross-bedded (Fig. 11b).

The artifact bearing KBS Tuff is well exposed along the Karari Escarpment and Koobi Fora Ridge. It is highly varied in lithology, thickness and general appearance thus only its stratigraphic position with respect to the Tulu Bor Tuff and an overlying sequence of coarse-grained large scale trough cross-bedded channel sandstones of variable thickness allows the KBS Tuff to be readily recognized in isolated outcrops at Ileret and between the Koobi Fora ridge and the mouth of the Laga Bura Hasuma (Fig. 11c).

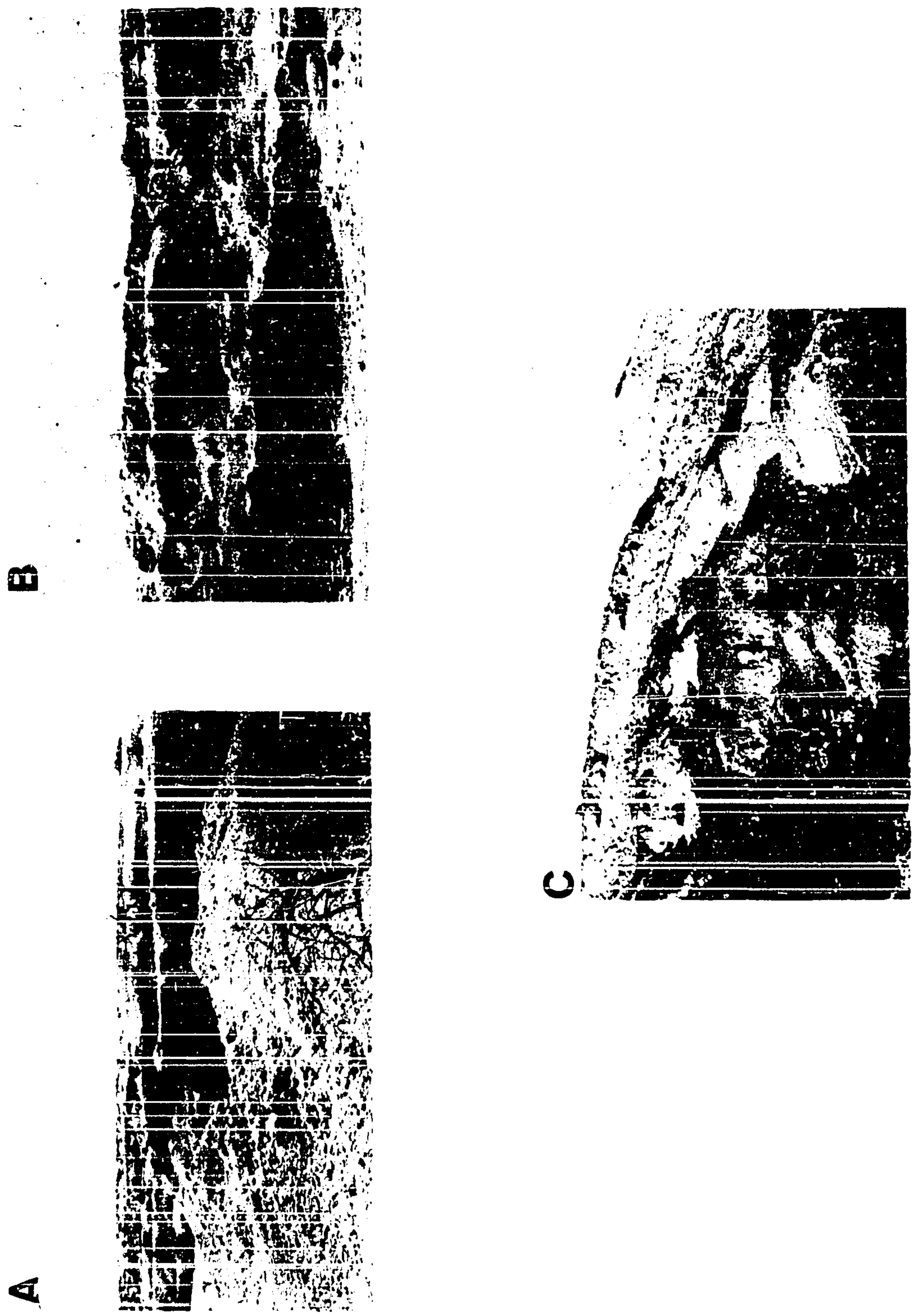
Tuffs above the KBS Tuff are of local occurrence and cannot be traced laterally for any great distance. The Chari, a 2 to 3 meter thick tuff, occurs along the top of the Ileret ridge. It is very light gray (N-8), to white (N-9), locally small-scale cross-bedded and contains large (15 centimeters in diameter) pumice cobbles (Fig. 12a). The Karari Tuff, 0.5 to 1 meter thick, caps the Karari escarpment (Fig. 12b). Although the Chari and Karari Tuffs cannot be physically correlated, the K-Ar dates obtained from sanidine crystals which occur in the pumice pebbles

Fig. 12. Photographs of the upper tuffs of the Koobi Fora Formation

a. Karari Tuff capping the Karari escarpment

b. Chari Tuff capping the Ileret ridge

c. Koobi Fora Tuff capping hogback near Koobi Fora spit


A
B
C

and cobbles and the oxygen isotope ratios of the glass shards (Fitch and Miller, 1974; Cerling, 1973) indicate that the two are correlative (Fig. 9). The Koobi Fora Tuff Complex is a 12 meter thick sequence of interbedded and intricately interfingering sandstone, siltstone and tuff units that are locally small-scale cross-bedded and contain gastropods (Fig. 12c). This complex is exposed along Koobi Fora ridge near Koobi Fora spit and cannot by physically correlated with any other tuff unit. K-Ar dates indicate that the complex is slightly older than either the Chari or Karari (Fitch and Miller, 1974) but oxygen isotope ratios permit correlation with the Chari and Karari Tuffs.

The Koobi Fora Formation was subdivided into two members in the Ileret area and in the Koobi Fora - Allia Bay areas (Bowen and Vondra, 1973). The subdivision was made because of lithogic differences between the sediments in the upper portion of the formation and those in the lower portion and the geographic restriction of the upper portion of the formation. Although the change in lithology occurs above the KBS Tuff at the base of local channel complexes, the top of the KBS Tuff was selected as the contact between the Lower Member and Ileret Member in the Ileret area and the Lower and Upper Members in the Koobi Fora - Allia Bay areas. The easily mapped KBS Tuff was chosen as the contact rather than the base of the channels because of the inherent difficulty in mapping and correlating channels. In order to avoid the confusion of having the KBS Tuff in both the Ileret and Upper Members, the top of the tuff was chosen as the contact rather than the base.

Type Section of the Koobi Fora Formation

Koobi Fora

Lake Rudolf, Kenya

This section was measured 6.6 km East of Koobi Fora spit at $3^{\circ}56'$ N latitude and $36^{\circ}15'$ E longitude.

Bed	Description	Thickness (meters)
	Plio-Pleistocene Koobi Fora Formation Total thickness 146.2 m	
56	Tuff; very light gray, N-8 to light gray, N-7; consists of very fine-grained glass shards; unit is tuff complex with interbeds of sand and silt; pumice pebbles up to 1 mm in diameter occur in bands; basal contact is very sharp; parallel laminated to thin bedded at top; litharenite is ripple-laminated and silt is lenticular-bedded; calcareous root casts and concretions occur locally; weathering zone occurs on silt in center section, peds 3 mm on a side, slickensides occur on peds; moderately well indurated and moderately resistant....................................	5.2
55	Sandstone; yellowish gray, 5Y7/2; feldspathic litharenite consists of medium-grained, subrounded moderately sorted grains of quartz, rock fragments, orthoclase; unit is calcareous; basal contact is very sharp; Kappa Type 1 ripple-laminations occur throughout; calcareous concretions are numerous; friable and nonresistant....................................	1.0
54	Sandstone; grayish to orange, 10YR7/4 interbedded with siltstone, pale yellowish brown, 10YR6/2; lithic arkose grading into a feldspathic litharenite, conglomerate to very fine-grained; consists of subrounded, very poorly sorted grains of quartz, orthoclase, rock fragments, mica; argillaceous, calcareous; basal contact is very sharp and erosional; large-scale Pi cross-beds grade upward to ripple-lamination; silts are lenticular-	

Bed	Description	Thickness (meters)
	bedded; capped by limonite clast intraformational conglomerate; gastropods occur at top; vertebrate fossils occur throughout; numerous calcareous root casts and calcareous concretions in silts; cuts 5.8 m into underlying units; channel, levee complex, well indurated but nonresistant.................	4.0
53	Sandstone; pale yellowish brown, 10YR6/2; arkose consists of medium-grained grains of quartz, orthoclase, rock fragments; calcareous; basal contact is very sharp; small interbeds of silt occur throughout; well indurated and resistant......................................	0.7
52	Sandstone; grayish orange, 10YR7/4; feldspathic litharenite consists of very fine-grained, subrounded, poorly sorted grains in quartz, rock fragments; argillaceous; limonite clasts occur laterally; calcareous; basal contact is very sharp; Kappa Type 1 ripple-laminated; calcareous root casts are common; loose to well indurated at top and nonresistant to resistant.............................	0.7
51	Sandstone, light olive brown, 5Y5/6 to pale yellowish brown, 10YR6/2; lithic subarkose very fine-grained becoming coarse-grained upward; consists of subrounded, very poorly sorted grains of quartz, clay, feldspar, rock fragments, mica; calcareous; basal contact is distinct; parallel laminations grade to ripple-laminations; silt lense in center is medium bedded; fish fossils and gastropods at top, well indurated at top and resistant at top......	2.0
50	Sandstone; light brown, 5YR5/6; feldspathic litharenite; consists of very fine-grained, subrounded, poorly sorted grains of quartz, rock fragments, feldspar, mica; argillaceous; basal contact is distinct; calcareous root casts and concretions are numerous; well indurated but nonresistant......................	0.6
49	Siltstone; pale yellowish brown, 10YR6/2; small sand lenses and sand-filled mud cracks are pale yellowish orange, 10YR8/2; grades	

Bed	Description	Thickness (meters)
	upward to coarse sand; basal contact is distinct; mud cracks, calcareous root casts and concretions are common lenticular bedding grades to medium bedded; limonite streaks and concretions occur throughout; blocky, well indurated and resistant............	4.0
48	Sandstone; yellowish gray, 5Y7/2; lithic arkose consists of very fine-grained, subrounded, moderated sorted grains of quartz, feldspar, rock fragments, mica; basal contact is distinct; parallel laminated with silt interbeds grades to Kappa Type 2 ripple-laminated; molluscs in lenses; calcareous root casts and concretions occur locally. lenticular bedded siltstone at base; loose and nonresistant................................	2.8
47	Claystone; pale yellowish brown, 10YR6/2; slightly sandy and limonitic; basal contact is very sharp; lenticular-bedded grades to thin-beds at top; breaks into large prismatic blocks; weathers fissile, unit is resistant.....	1.4
46	Siltstone; grayish red, OR5/2 grades to pale yellowish brown, 10YR6/2; very sandy and calcareous; basal contact is gradual transition slow; lenticular-bedded to thin bedded upward; limonite-filled root casts and concretions occur throughout; sand-filled mud cracks at top, molluscs at top in small sand channel; breaks into prismatic blocks, well indurated and resistant....................	1.3
45	Sandstone; yellowish gray, 5Y7/2; feldspathic litharenite, is fine to medium-grained; subrounded, poorly sorted; composed of quartz, rock fragments, mica, clay, feldspar; calcareous; basal contact is very sharp; parallel laminated at base with clay laminae; massive at top; molluscs throughout capped by calcareous concretionary layer; loose and nonresistant......................................	1.0
44	Sandstone; pale brown, 10YR6/2; mottled moderate brown, 10YR5/4 grades to grayish orange, 10YR7/4 mottled moderate brown,	

Bed	Description	Thickness (meters)
	10YR5/4; feldspathic litharenite is very coarse to coarse-grained, well rounded, very poorly sorted; consists of rock fragments; quartz, feldspar, clay; calcareous; basal contact is very sharp; coarse sand lenses at base; ripple-lamination at top; algal heads _in situ_ near top, molluscs at top, calcareous root casts at top, limonitic root casts at base, vertebrates throughout; well indurated and resistant....................	2.0
43	Sandstone; pale yellowish brown, 10YR6/2; lithic arkose is very fine-grained, subrounded, very poorly sorted grains of quartz, feldspar, rock fragments; argillaceous at base, calcareous at top; basal contact is distinct; parallel laminated to ripple-laminated; Kappa Type 1; coarse lenses at base, molluscs in coarse lenses, calcareous root casts at top; laterally mollusc unit become resistant, concretionary weathering and resistant....................................	3.0
42	Sandstone; pale yellowish brown, 10YR6/2; feldspathic litharenite is very fine-grained, very poorly sorted and consists of quartz, clay, rock fragments, feldspar, mica; basal contact is distinct; parallel laminated with laminated clay interbeds at top, coarse sand lenses at base, molluscs near base; friable and nonresistant.............................	1.2
	Sandstone, as unit 40 below.....................	0.1
41	Claystone, as unit 39 below.....................	0.3
40	Sandstone; grayish orange, 10YR7/4; subarkose is very fine-grained, well sorted grains of quartz, feldspar, mica; calcareous; basal contact is very sharp; contains mulluscs; loose and nonresistant.........................	0.1
39	Claystone; moderate brown, 5YR3/4; calcareous; basal contact is very sharp; thin bedded; limonite streaks at base, calcareous root casts and concretions at top; saline, well indurated but nonresistant....................................	0.3

Bed	Description	Thickness (meters)
38	Sandstone; pale yellowish brown, 10YR6/2; sublitharenite is very fine-grained subrounded, poorly sorted consisting of rock fragments, clay, quartz; calcareous and limonitic; basal contact is very sharp; parallel laminations grade to Kappa Type 2 ripple-laminations to large-scale highly contorted Pi cross-beds S 64° W; grades back to ripple-laminations to parallel laminations; molluscs at top, vertebrates in cross-bedded units, coarse sand lenses at base, clay lenses at top, limonite streaks at top; well indurated and resistant........................	6.2
37	Sandstone; pale yellowish brown 10YR6/2; interbedded with sandy siltstones, olive gray, 5Y4/1; basal contact is gradual transitional rapid; parallel laminated to thin-bedded; limonite root channels and molluscs at base, limonite clasts in capping unit; well indurated but nonresistant......	4.4
36	Tuff; very pale orange 10YR8/2; very fine-grained to argillaceous consisting of glass, clay; basal contact is very sharp; parallel laminated goes to ripple-laminated, Kappa Type 1; calcareous root casts at top; lenticular unit; fractures into prismatic blocks; well indurated and resistant..................	1.1
35	Sandstone; yellowish gray; 5Y8/4; feldspathic litharenite is very fine to fine-grained, subrounded, moderately sorted consisting of rock fragments, feldspar, mica, quartz; argillaceous; basal contact is gradual transition slow; parallel laminated with interbeds of lenticular-bedded silt grades upward to ripple-laminations Kappa Type 1; calcareous root casts and concretions in sand, limonitic concretions in silt, molluscs in upper 1.5 m, loose to well indurated and nonresistant.....................	3.0
34	Siltstone; pale yellowish brown, 10YR6/2 to grayish red, 10R4/2 mottled light olive gray 5Y6/1 to very light gray, N-8; sandy at base; saline and limonitic throughout; basal contact is distinct; thin bedded; sand lenses occur	

Bed	Description	Thickness (meters)
	at base, limonite root channels and concretions at base, calcareous root casts increase upward; well indurated and moderately resistant..................................	3.0
33	Sandstone; grayish orange, 10YR7/4; streaked dark yellowish orange, 10YR6/6; lithic arkose, consisting of rock fragments; clay, quartz, feldspar, mica; calcareous; basal contact is very sharp; small-scale Pi cross-beds; calcareous root casts are numerous, upper half goes laterally to conglomerate with large-scale Pi cross-beds and vertebrate fossils; grades upward to ripple-lamination, well indurated and resistant.....................................	4.8
32	Sandstone; dark yellowish orange, 10YR6/6; subarkase consisting of fine to coarse-grained, moderately rounded, poorly sorted grains of quartz, feldspar, mica, rock fragments; calcareous; basal contact is very sharp and irregular; small-scale Pi S 66° W that grade to ripple-laminations; molluscs at top, vertebrates throughout; well indurated and resistant..................................	0.6
31	Siltstone; pale yellow brown 10YR6.5/3; very sandy; basal contact is very sharp and irregular; thin bedded; contains leaf impressions, limonite streaked, selinite in veins; blocky, well indurated but nonresistant.................	0.4
30	Sandstone; grayish orange, 10YR7/4; feldspathic litharenite consisting of medium-grained, subrounded, moderately sorted grains of rock fragments, feldspars, mica, quartz; calcareous; basal contact is very sharp; large-scale Pi cross-beds grade to ripple-lamination; root casts, loose and nonresistant.....................................	0.5
29	Siltstone; pale yellowish brown, 10YR6.5/3; streaked dark yellowish orange, 10YR6/6; slightly sandy and argillaceous; basal contact is very sharp; thin bedded to parallel laminated at top; limonite streaks, well	

Bed	Description	Thickness (meters)
	indurated but nonresistant......................	2.0
28	Carbonate; yellowish gray, 5Y8/4 grades to very light gray, N-8; packed biosparudite with silty sand unit at base; grades up to sandy carbonate; contains very fine-grained sand and consists of coarsely crystalline carbonate; basal contact is distinct; allochems are gastropods and pelecypods, fossils are slightly abraded; well indurated and resistant............................	3.0
27	Conglomerate; dark yellowish orange, 10YR6/6; consists of polymictic, well rounded, moderately sorted, spherical to rectangular granules of orthoclase, green ignibrites, basalt, quartzite, quartz, mica; basal contact is distinct; small-scale Pi cross-beds .5 m up from base to top; vertebrates throughout, locally calcareous, locally well indurated but nonresistant..................................	3.5
26	Sandstone; yellowish gray, 5Y8/4 grades to pale yellowish brown, 10YR6/2; feldspathic litharenite consisting of very fine-grained, well rounded, poorly sorted, rock fragments, quartz, clay, feldspar; basal contact is distinct; parallel laminations grade to thin beds; lenses of gastropods occur throughout, limonitic root casts are common, friable and nonresistant......	4.1
25	Tuff; very light gray, N-8; consists of fine-grained, glass shards, clay, quartz, mica, "heavies"; basal contact is very sharp; thin bedded to parallel laminated; sand-filled root casts are numerous; friable but resistant, KBS Tuff..	1.2
24	Siltstone and sandstone interbeds as unit 19 below covered with talus, section examined by digging holes at periodic intervals, appears to be thin bedded to ripple-laminated, numerous molluscs at top, basal contact is very sharp, loose nonresistant............................	6.3
23	Carbonate; grayish yellow, 5Y8/4 to grayish orange, 10YR7/4; packed gastropod biosparudite consisting of calcite, quartz, rock fragments;	

Bed	Description	Thickness (meters)
	basal contact is very sharp; sandstone at base grades up to carbonate; well indurated and resistant..................................	0.8
22	Tuff; very pale orange, 10YR8/2; gone to clay; basal contact is very sharp; highly contorted ripple-laminations, clay filled root channels occur locally, well indurated and nonresistant..................................	0.2
21	Siltstone; yellowish gray, 5Y7/2; as unit 19 below; basal contact is gradual transition slow; contains resistant mulluscan sands large-razor clams and gastropods; well indurated and moderately resistant..............	7.6
20	Sandstone; grayish orange 10YR7/4; feldspathic litharenite consisting of very fine-grained, well rounded, moderately sorted grains of rock fragments, quartz, feldspar, mica; very calcareous; basal contact is gradual transition slow; parallel laminated; well indurated and resistant....................	1.5
19	Siltstone; yellowish gray, 5Y7/2; sandy, argillaceous and limonitic; basal contact is gradual transition slow; thin bedded with occasional sand lenses that are ripple laminated and contain gastropods; potato and plate shaped limonite concretions occur along bedding planes; selenite occurs in fractures; gastropods scattered throughout; well indurated but nonresistant..............................	18.5
18	Tuff; very light gray, N-8; with thin bands of light gray N-7; medium to fine grain with high admixture of sand; glass shards goes laterally to clay; basal contact is very sharp to laterally gradual transition slow; lenticular, thins from 3 to .2 m in 125 m; parallel laminated to distorted laminations at top, well indurated and locally resistant..................................	3.0-0.2
17	Siltstone; olive gray, 5Y6/1; argillaceous, locally sandy; basal contact is very sharp; parallel laminated; limonite concretions along bedding planes, selenite in joints,	

Bed	Description	Thickness (meters)
	well indurated but nonresistant................	1.6
16	Carbonate as unit 6 below......................	0.2
15	Claystone as unit 8 below......................	0.6
14	Carbonate as unit 6 below......................	0.6
13	Siltstone as unit 5 below......................	0.6
12	Carbonate as unit 6 below......................	0.3
11	Covered..	2.9
10	Carbonate as unit 6 below......................	0.3
9	Covered..	2.7
8	Claystone; pale yellowish brown, 10YR6/2; bentonitic and saline; basal contact is distinct; limonitic; parallel laminated; very deeply weathered and nonresistant.....................	6.3
7	Covered..	6.6
6	Carbonate; very pale orange, 10YR8/2; packed ostracod biosparite consisting of very coarse calcite; basal contact is very sharp; medium bedded; ripple marks on upper surface; broken 15 cm x 30 cm blocks; well indurated and resistant.......................................	0.4
5	Siltstone; dark yellowish brown, 10YR4/2; bentonitic and very sandy; basal contact is covered; parallel laminated; limonite concretions, fish fossils are numerous; friable and nonresistant................................	0.7
4	Covered..	10.0
3	Claystone; light yellowish orange 10YR8/6; with interbeds of Tuff, very light gray, N-8; slightly limonitic; basal contact is covered; parallel laminated, well indurated but nonresistant.............................	3.4
2	Covered..	4.2

Bed	Description	Thickness (meters)
1	Tuff; very light gray, N-8; limonitic and argillaceous; very siliceous at surface; basal contact is covered; parallel laminated; very porous, well indurated and resistant........................	1.2

Lower Member

The Lower Member as designated by Bowen and Vondra (1973) consists of the portion of the Koobi Fora Formation below the upper contact of the KBS Tuff. The unit outcrops extensively east of the Ileret ridge to the Suregei cuesta and south of the Kokoi horst complex to Derati. At the margin of the basin east of Ileret the Lower Member consists of a series of thick (4 meters), loose molluscan subarkoses capped by thin (.1 to .5 meters) bioclastic carbonates with occasional lenses of thin conglomerates and siltstones. This sequence thins slightly toward the south near the Karari escarpment and interfingers with interbedded thick (3 meters) claystones and thin (0.1 to 0.3 meters) bioclastic carbonates. Vertically these are truncated by 53 meters of intercalated small-scale planar cross-bedded, medium-grained sublitharenite and lenticular-bedded, mud cracked siltstones which contain calcareous root casts. This coarse clastic sequence is followed by the Tulu Bor Tuff and overlying thin parallel laminated, limonitic siltstones which contain occasional lenses of gastropods. The strata above the siltstones are characterized by an increase in average grain size. They consist of eight fining upward cycles from conglomerate to siltstone. These cycles interfinger westward along the Karari escarpment with medium-grained ripple-laminated feldspathic litharenites, thin bioclastic carbonates which are occasionally capped by algal stromatolites, parallel laminated to lenticular-bedded siltstones and intraformational conglomerates with limonite clasts. This sequence contains numerous vertebrate fossils including hominid cranial and post-cranial remains (Fig. 13). The average grain-size tends to decrease toward Koobi Fora spit. The sequence grades into and interfingers with 10 meter thick sequences of parallel laminated, limonitic siltstones capped by thin bioclastic carbonates with an occasional lense of fine-grained molluscan lithic subarkoses. South of Koobi Fora spit near the mouth of Laga Bura Hasuma, the Lower Member consists of a sequence of interbedded thin bioclastic carbonates and siltstones which grade vertically into 37 meters of planar cross-bedded, medium-grained sandstones above the Tulu Bor Tuff. Thin algal stromatolite units and bioclastic carbonates interfinger with these sandstones toward the north and east. The thickness of the Lower Member varies from 123 meters along the basin margin to 78 meters near the Koobi Fora spit. Although the KBS Tuff could not be located in the exposures near the mouth of the Laga Bura Hasuma, the thickness of the Lower Member appears comparable to the sequence near the Koobi Fora spit.

Upper Member

The Upper Member of the Koobi Fora Formation (Bowen and Vondra, 1973) outcrops along the Karari escarpment and Koobi Fora ridge, in isolated exposures between the Kokoi horst complex and the Koobi Fora ridge and south to Shin and Laga Bura Hasuma. Along the Karari escarpment and the eastern end of the Koobi Fora ridge, the Upper Member is

Fig. 13. Photographs of the Lower Member, Koobi Fora Formation

a. Suregei Tuff Complex showing typical exposure in the Ileret area

b. Suregei cuesta dips toward Lake Rudolf at about 2° and forms the basement on which the Upper Cenozoic sediments were deposited

c. Alluvial fans composed of basalt cobble occur in the basal Lower Member

d. The boulder conglomerates in the alluvial fans are interbedded with lacustrine claystones

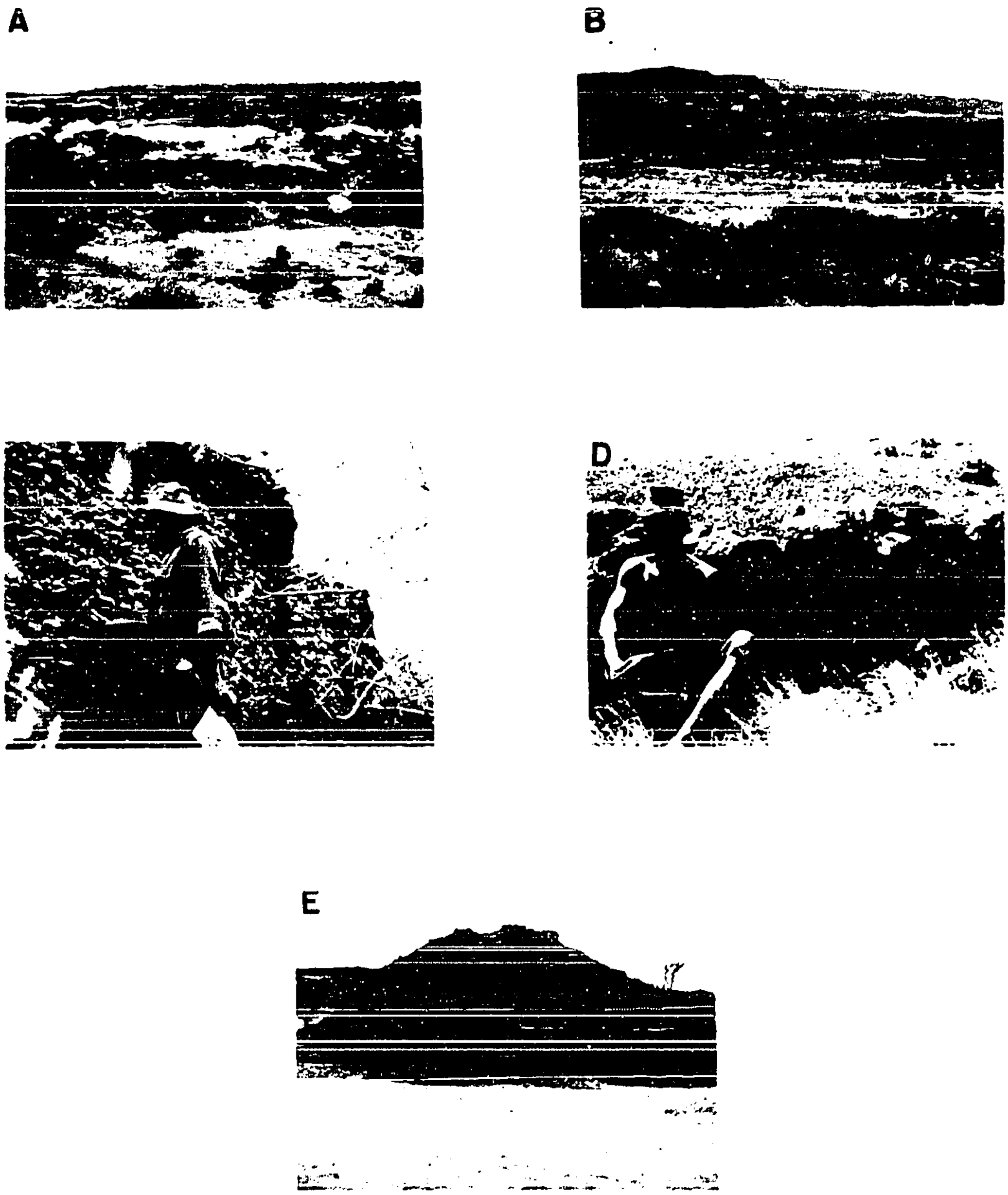
e. Typical exposure of Lower Member near Koobi Fora spit

A

B

D

E



characterized by large-scale trough cross-bedded sandstones, basalt cobble conglomerates, tuffaceous, lenticular-bedded siltstones and thin tuffs which disconformably overlie the Lower Member. Here the upper portion of the Upper Member contains occasional vertebrate fossils but numerous artifacts. These units decrease in thickness and average grain-size toward Koobi Fora spit and interfinger with fine-grained sandstones which locally contain lenses of granule conglomerate, bioclastic carbonates and algal stromatolites and are interbedded with occasional parallel laminated or lenticular-bedded siltstones and tuffs. The Upper Member thickens westward from 43 meters along the Karari escarpment to its maximum of 88 meters near the Koobi Fora spit. It then thins to 6 meters southward to Shin (Fig. 14).

The disconformable relationship between the Upper and Lower Members along the Karari escarpment and the eastern portion of the Koobi Fora ridge is marked by local downcutting of a complex of channel conglomerates and sandstones. These erosional surfaces which may display as much as 8 meters of relief can be traced locally into caliches or into laminated fine-grained sandstones which are apparently conformable. Near Koobi Fora spit the relief on the erosional surfaces decrease to zero and the disconformity appears to grade into conformity.

Ileret Member

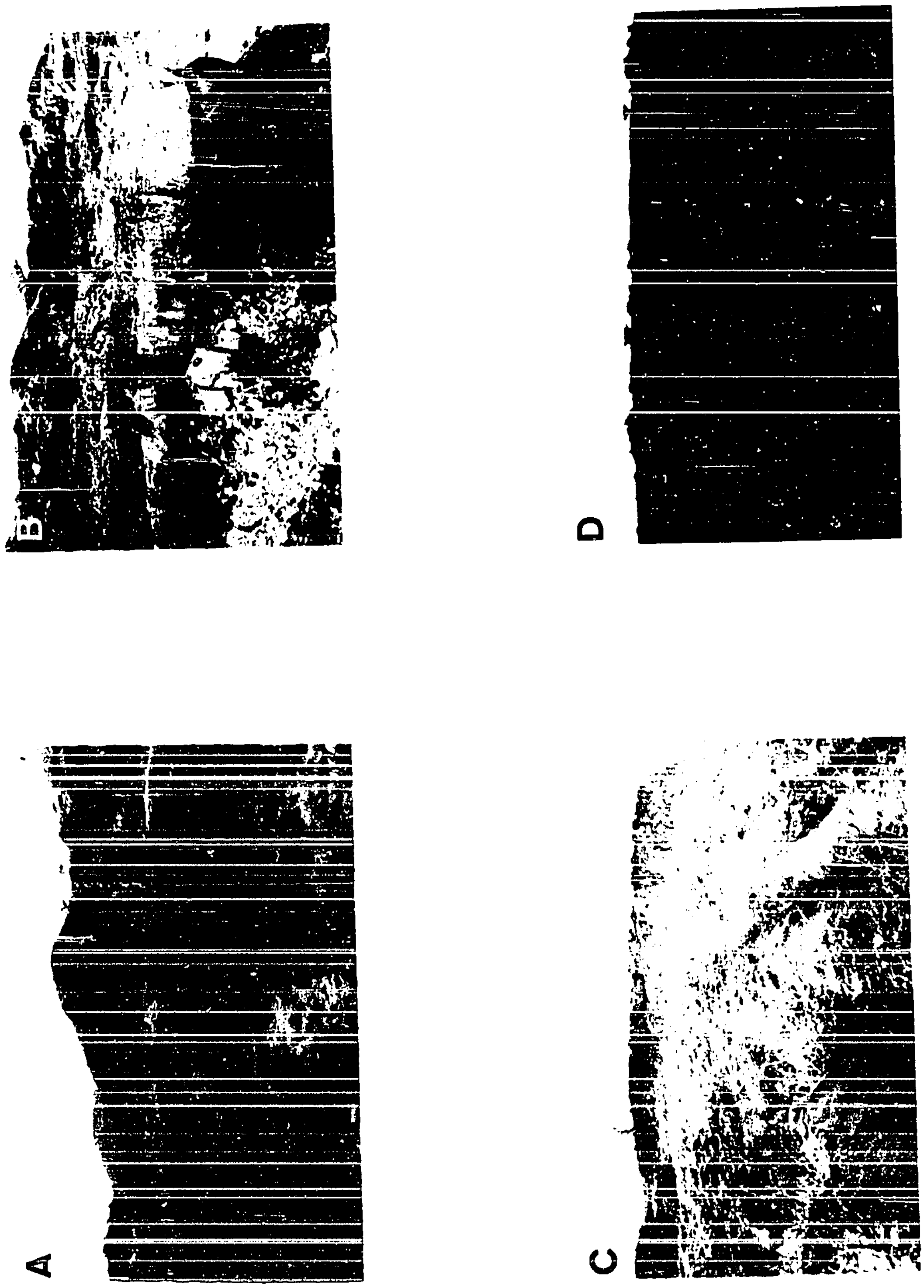
The beds in the Ileret area which were informally designated the "lower unit" (Vondra et al., 1971) are lithologically homogeneous and are geographically restricted to the Ileret ridge. The term Ileret Member was proposed for the beds which lie between the upper contact of

Fig. 14. Photographs of the Upper Member, Koobi Fora Formation

a. Basal portion of Upper Member showing channeling into Lower Member

b-c. Lenticular tuffs occur through the upper portion of the Upper Member

d. Exposure of Upper Member show little relief and are locally covered by vegetation


B
D
A
C

the KBS Tuff in the Ileret area and the top of the Chari Tuff which caps the Koobi Fora Formation (Bowen and Vondra, 1973). Exposures located in the Ileret area at 4°16' N latitude and 36°15' E longitude (HBH 6173, East Africa Grid) were designated as the type locality (Fig. 6).

Since the Ileret Member is restricted to a very small area it exhibits little lateral variation from one end of the exposures to the other. Immediately above the KBS Tuff, the Ileret consists of a series of interbedded thin bioclastic carbonates and fine-grained molluscan subarkoses which grade laterally and vertically into fine-grained small-scale trough cross-bedded subarkoses containing vertebrate fossils. This sequence continues as an upward coarsening sequence. Lenticular conglomerates and coarse-grained trough cross-bedded sublitheranites are interbedded with tuffaceous lenticular-bedded siltstones and parallel-laminated to ripple-laminated tuffs. One exception to this coarsening upward sequence is a laterally continuous fine-grained, very pale orange, 10YR8/2, loose subarkose which contains numerous disarticulated fish fossils and is capped by a thin carbonate unit. This occurs about 8 meters below the Chari Tuff (Fig. 15).

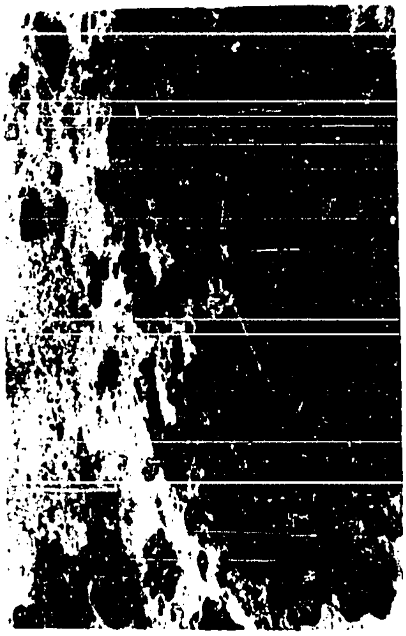
There are no localities where the entire Ileret Member is exposed in a continuous sequence from bottom to top although at the type locality only the base of the unit is not exposed. The compiled thickness of the Ileret Member is 89 meters (Fig. 10). The entire unit contains vertebrate fossils but they are more numerous in the upper portion. Hominid fossils and artifacts occur here as well.

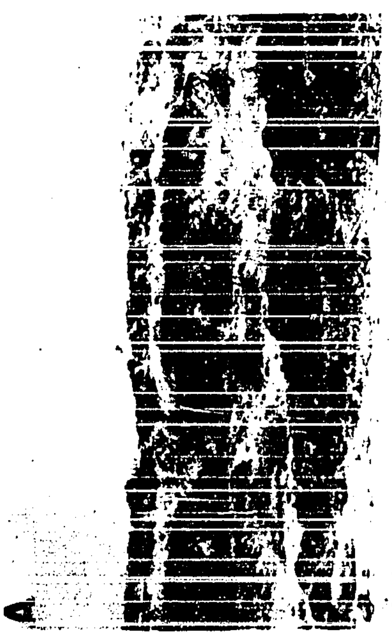
Fig. 1[illegible]. Photographs of the Ileret Member, Koobi Fora Formation

a. Upper portion of Ileret Member showing distributary channel, floodbasin siltstones and Chari Tuff

b. Outcrop of ripple marked algal stromatolite unit in lower portion of Ileret Member

c. Lenticular tuff outcrop which occurs in middle portion of Ileret Member





Type Section of the Ileret Member

of the Koobi Fora Formation

Ileret

Lake Rudolf, Kenya

This section was measured 4 km S 40° E of the Ileret police post at 4°16' N latitude and 36°15' E longitude.

Bed	Description	Thickness (meters)
	Pleistocene Series Ileret Member Koobi Fora Formation Total Thickness 59.5 m	
36	Tuff; very light gray, N-8, with white, N-9 lense at base and top; consisting of very fine-grained, glass shards and locally containing pumice pebbles up to 15 cm in diameter; basal contact is irregular and very sharp; thinly bedded at base and top and parallel laminated in center; firable but resistant..................	1.6
35	Siltstone; moderate brown, 5YR4/4; slightly to very argillaceous; basal contact is gradual with transition rapid; parallel laminations in lower half; root casts, calcareous concretions occur throughout; well indurated, nonresistant..................	2.7
34	Claystone; pale red, 5R6/2; basal contact is very sharp; thinly bedded; calcareous root casts and fish fossils occur throughout; mottled green limestone at base, well indurated but nonresistant....................	3.0
33	Siltstone; very pale orange, 10YR7/2; very micaceous, and very sandy; basal contact is distinct; parallel laminations at base with lenticular beds upward; root casts and concretions are numerous; well indurated but nonresistant..............................	5.0

Bed	Description	Thickness (meters)
32	Sandstone; moderate yellowish brown, 10YR5/4; lithic subarkose consisting of medium-grained, spherical, rounded, moderated well sorted grains of quartz, feldspar, rock fragments; basal contact is very sharp; cross-bedded, grouped, small-scale, nonerosional, trough, heterogeneous, Nu, S 10° E, line of flow distinct, N-S, pointing distinct; crocodile, mammal fossils are numerous; moderately well indurated and resistant........	0.2
31	Claystone; moderate brown, 5Y4/4; slightly calcareous; basal contact is very sharp; parallel laminated; calcareous concretions occur throughout; well indurated but nonresistant........................	2.9
30	Sandstone; grayish orange, 10YR7/4; subarkose consists of medium to very coarse-grained, spherical, subrounded grains of quartz, orthoclase, plagioclase, chert; calcareous; basal contact is distinct and erosional; cross-beds, grouped, small-scale, nonerosional, Nu, trough, heterogeneous, N 22° E, line of flow and pointing distinct NE - SW; vertebrate fossils are abraded; cuts 5.3 m into underlying units; well indurated; resistant..............	3.0
29	Siltstone; grayish orange, 10YR8/4; slightly argillaceous and very sandy; basal contact is very sharp; lenticular-bedded; calcareous root casts, thin clay lenses occur throughout; well indurated but nonresistant...........	5.1
28	Siltstone; pale yellowish brown, 10YR6/2; grades vertically into sandstone that is yellowish gray, 5Y8/1 and a lithic subarkose; it is argillaceous to very coarse and consists of subrounded, poorly sorted grains of quartz, clay, orthoclase, rock fragments; lenticular-bedded silts with calcareous root casts and concretions; sand is trough cross-bedded with Nu type very indistinct; vertebrate fossils are abundant; well indurated and resistant................................	1.0

Bed	Description	Thickness (meters)
27	Sandstone; very pale orange, 10YR8/2; lithic subarkose consisting of fine-coarse-grained, spherical, subrounded, moderately sorted grains of quartz, orthoclase, rock fragments, chert; basal contact is distinct and irregular; shows graded bedding; contains calcareous root casts, fish fossils, clay galls; well indurated and resistant........................	0.6
26	Siltstone; dark yellowish brown, 10YR4/2; very sandy upper 1.5 m and very argillaceous at base; basal contact is gradual transition rapid; parallel laminated; contains calcareous root casts and is blocky; well indurated but nonresistant............................	2.8
25	Sandstone; very pale orange, 10YR8/2; to dark yellowish orange, 10YR6/6; lithic subarkose is very fine-grained, moderately sorted, subrounded grains of quartz, orthoclase, rock fragments, clay; basal contact is gradual transition slow; ripple-laminated with Kappa Type 2; contains calcareous root casts; friable but slightly resistant..........	0.8
24	Sandstone; dark yellowish orange, 10YR6/6; arkose consisting of coarse-grained, poorly sorted, subrounded grains of feldspar, mica, quartz, hornblende, "heavies"; basal contact is very sharp; trough cross-bedded with Nu, type being indistinct; contains calcareous root casts, clay galls; well indurated but mostly covered................................	1.4
23	Claystone; grayish red, 5R5/2; slightly silty and locally calcareous; basal contact is very sharp; lenticular-bedded; calcareous root casts and concretions are numerous; well indurated but nonresistant.....................	1.0
22	Sandstone; yellowish gray, 5Y8/1; lithic subarkose composed of coarse-grained, spherical, rounded, moderately sorted grains of quartz, feldspar, rock fragments; basal contact is very sharp; small-scale trough cross-beds of type Nu dipping N 18° W; well indurated and resistant........................	0.3

Bed	Description	Thickness (meters)
21	Siltstone; very pale orange, 10YR7/2; very argillaceous to sandy at top; basal contact is very sharp; parallel laminations to lenticular-bedded at top; calcareous root casts and concretions are numerous; well indurated but nonresistant......	0.3
20	Sandstone; moderate yellowish brown, 10YR6/3; lithic subarkose grades coarse to fine-grained and is composed of high sphericity, rounded, moderately sorted grains of feldspar, quartz, rock fragments, "heavies"; calcareous; basal contact is sharp and irregular; ripple-laminations at base that are curved, continuous and asymmetrical, singular with an amplitude of 2 cm and a wave length of 30 cm dipping N 74° W, grades upward to cross-beds that are grouped, large-scale, nonerosional, trough, heterogeneous, Nu, N 83° W; internal graded bedding is apparent; calcareous concretions, clay galls, mammal fossils-abraded are common; well indurated and resistant.......	1.9
19	Covered..	0.5
18	Sandstone; yellowish gray, 5Y8/1; lithic subarkose composed of coarse-grained, high sphericity, rounded, moderately sorted grains of quartz, feldspar, rock fragments, mica, "heavies"; basal contact is very sharp; unit contains cross-beds that are grouped, small-scale, trough, nonerosional, heterogeneous, Nu, N 18° W, line of flow and pointing distinct SE-NW; shows concretionary weathering, well indurated and resistant..................	0.5
17	Siltstone; very pale orange, 10YR8/2; sandy at base and at top; limonitic throughout; basal contact is distinct; lenticular-bedded; limonite root casts and concretions are common; blocky, well indurated but nonresistant.....................................	0.6
16	Sandstone; yellowish brown, 10YR6/2; lithic subarkose composed of very fine-grained, rounded, very poorly sorted grains of quartz, feldspar, clay, rock fragments; basal contact is very sharp; very well indurated and resistant..	0.2

Bed	Description	Thickness (meters)
15	Tuff; light gray, N-7; consists of very fine-grained glass; basal contact is very sharp and irregular; parallel laminations are contorted and dip N 15° E, silt lenses and mud cracks occur along base; small calcareous root casts and concretions occur throughout; friable but resistant..............	0.3
14	Sandstone; grayish orange, 10YR7/4 to yellow gray, 5Y7/2, to pale yellowish brown, 10YR 5/2; lithic subarkose consisting of very fine to medium-grained, spherical, subrounded, moderately sorted grains of quartz, feldspar, rock fragments, clay; basal contact is very sharp and irregular; lenticular-bedded; argillaceous sand at base grades to ripple-laminated Kappa Type 2; calcareous root casts, clay pods occur in upper section; friable to well indurated and nonresistant................	2.8
13	Sandstone; moderate yellowish brown 10YR5/4, to grayish orange, 10YR7/4 to dark yellowish brown, 10YR4/2; sublitharenite consisting of very fine to medium-grained, spherical, subangular, poorly sorted, grains of quartz, rock fragments, clay; calcareous; basal contact is covered; calcareous root casts are abundant, caliche at top; well indurated and resistant................................	2.7
12	Sandstone; grayish orange, 10YR7/4; subarkose consisting of coarse-grained, locally conglomeratic, well rounded, very poorly sorted grains of feldspar, quartz, mica, rock fragments; basal contact is very sharp and erosional; contains cross-beds that are grouped, small-scale, erosional, trough, heterogeneous, Pi, S 20° E, line of flow and pointing distinct, NW - SE; vertebrate fossils and crotovina occur throughout concretionary weathering and resistant................................	0.3
11	Sandstone as unit 7, shows graded bedded, 4 cycles noted, contains Etheria, form prominent ledge, cuts 3 m into units below.....	3.0
10	Sandstone, as unit 4, load casts at base of channel..	5.2

Bed	Description	Thickness (meters)
9	Sandstone as unit 4..............................	0.3
8	Conglomerate lithic subarkose grades to claystone as unit 7........................	1.6
7	Polymictic conglomerate grades to claystone, contains limonite clasts and shows graded bedded, crotovina 7 cm in length and 5 cm in diameter, as unit 4....................	0.9
6	Sandstone grades to claystone as unit 4........	0.5
5	Sandstone grades to claystone as unit 4........	0.9
4	Sandstone grades to claystone; grayish orange, 10YR7/4 to dark yellowish orange, 10YR6/6 to moderate brown, 5 YR3/4; lithic subarkose composed of coarse grades to fine-grained, spherical, subrounded, moderately sorted grains of quartz, feldspar, rock fragments, mica, clay; locally limonitic and calcareous; basal contact is very sharp and erosional; cross-beds grade to ripple-lamination from grouped, heterogeneous, erosional, trough, small-scale, Nu, West to Kappa Type 3 N 50° W, angle of dip = 16°, calcareous root casts, vertebrate fossils occur throughout, mud cracks occur along base, claystone is thin bedded, friable to well indurated, resistant to nonresistant...	1.7
3	Sandstone; grayish orange, 10YR7/4 to dark yellowish orange, 10YR6/6; lithic subarkose consisting of very fine to medium-grained, spherical, subrounded, moderately sorted grains of quartz, feldspar, rock fragments, clay, limonite; calcareous; basal contact is distinct; cross-bedded with small-scale Nu in lower sand; represents series of channels capped by sandy claystone; upper sand is cross-bedded with small-scale Nu that is grouped, heterogeneous, erosional, N 75° W, pointing and line of flow doubtful and indistinct; vertebrate fossils, calcareous root casts occur throughout; clay lenses and mud cracks occur at base; well indurated and resistant....	1.9

Bed	Description	Thickness (meters)
2	Claystone; dark yellowish brown, 10YR4/2 to moderate yellowish brown, 10YR5/4; silty and saline; basal contact is distinct; thin bedded; limonite concretions along bedding planes; blocky, well indurated but non-resistant..	1.2
1	Sandstone; light olive brown, 5Y5/6; lithic subarkose consisting of very fine to medium-grained, spherical, subangular, poorly sorted grains of quartz, feldspar, rock fragments; argillaceous; basal contact is unknown; local concentration of clay; friable and nonresistant..	0.8

Guomde Formation

The strata overlying the Chari Tuff and underlying the sequence of Holocene, gray diatomaceous siltstones were named the Guomde Formation (Bowen and Vondra, 1973) (Fig. 16). The name of the formation is taken from Kolum Guomde, a tributary of the Laga Tulu Bor which dissects the southern end of the Ileret ridge. The formation is restricted to the Ileret ridge and is best exposed at the southern and northern ends of the ridge. The exposures located at 4°18' N latitude and 36°15' E longitude (HBH 625752) although faulted at the base best illustrate the lithology of the formation and were designated the type locality (Bowen and Vondra, 1973). The Guomde comprises the middle unit at Ileret as originally defined by Vondra et al. (1971).

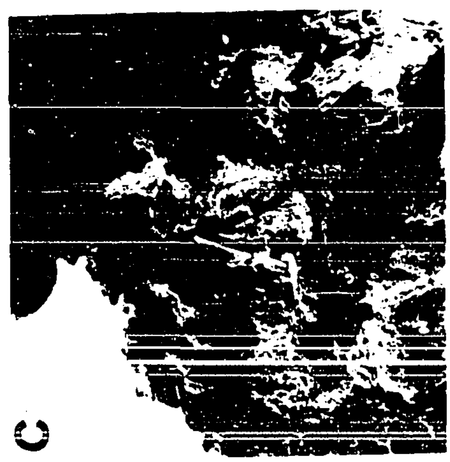
The unifying features of this unit are the sequence of the beds, the yellowish gray (5Y6/2) to light olive brown (5Y6/6) laminated siltstones and the intercalated thin bioclastic carbonates. Lying disconformably on the Koobi Fora Formation the basal unit consists of a 4

Fig. 16. Photographs of the Guomde Formation

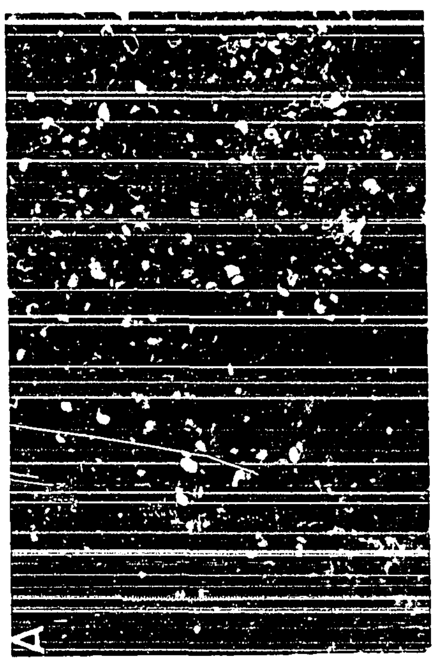
a. Bioclastic carbonate which is typical of the Guomde Formation

b. Floodbasin deposits containing rootcast in upper fluvial unit

c. Floodbasin deposits containing crotovina on lower fluvial unit



C



A

meter thick trough cross-bedded arkosic conglomerate which grades upward into lenticular-bedded siltstones that contain numerous large crotovina. This is followed by laminated siltstone and lithic arkoses and interbedded thin molluscan carbonates. A lenticular tuff occurs in the middle of this sequence. The uppermost units are trough cross-bedded coarse-grained subarkoses, lenticular-bedded siltstones and a lenticular tuff. The northern sequence is cut by many faults the last of which truncates the formation at the upper tuff. In the southern sequence only the base is faulted out. The Guomde Formation appears to thicken toward the south along the ridge from 32 to more than 37 meters but this variation may be due to subsequent erosion and faulting (Fig. 16).

Type Section of the Guomde Formation

Ileret

Lake Rudolf, Kenya

This section was measured 3 km S 70° E of the Ileret police post at 4°18' N latitude and 36°15' E longitude.

Pleistocene Series
Guomde Formation
Total Thickness 35.2 m

Bed	Description	Thickness (meters)
10	Sandstone; yellowish gray, 5Y7/2; lithic subarkose, composed of poorly sorted, very fine to very coarse, spherical, subrounded, grains of quartz, feldspar, rock fragments and is argillaceous and calcareous; basal contact is sharp and irregular; interbedded with very argillaceous sand and lenses of pebbles; contains disarticulated fish fossils and calcareous root casts; moderately well indurated and resistant.........................	6.0
9	Interbedded lithic arkoses, packed biosparudites and a tuffaceous mudstone, pale	

Bed	Description	Thickness (meters)
	yellowish brown, 10YR6/2, dark yellowish orange, 10YR6/6 and very pale orange, 10R8/2 respectively; arkoses are fine to coarse-grained, spherical, well rounded, poorly sorted grains of quartz, feldspar, rock fragments; argillaceous and calcareous; basal contact is distinct and irregular; contains disarticulated fish fossils; grades upward to mudstone to slightly silty then back to sand and to bioclastic carbonate containing stem kerns of pelecypods and gastropods, disarticulated fish fossils; <u>in situ</u> limonite concretions cap unit; resistant...........................	9.0
8	Sandstone; yellowish gray, 5Y7/2; lithic subarkose consisting of fine to very coarse, with occasional pebble lenses, spherical, rounded, very poorly sorted grains of quartz, orthoclase, rock fragments, "heavies"; clay, calcareous, basal contact is very sharp and irregular; contains silt lenses that are parallel laminated, unit is ripple-laminated, contains disarticulated fish fossils; calcareous root casts and concretions are abundant; capped by lenticular tuff that is 5 m thick; moderately well indurated but nonresistant..................................	4.1
7	Tuff; very pale orange, 10YR8/2; sandy and locally argillaceous consisting of fine-grained glass shards; basal contact is very sharp; thins laterally to .3 m; lower zone is thinly laminated with root casts, gastropods and calcareous concretions; upper zones show color bands which are probably weathering zones; well jointed, well indurated and resistant..........................	3.0
6	Sandstones; pale yellowish brown, 10YR6/2 interbedded with mudstones, light olive brown, 5Y6/6 and a 3 cm thick tuff near base; lithic subarkose consisting of very fine-grained, poorly sorted grains; basal contact is distinct; contorted bedding is prevalent; mudstone is parallel laminated and contains mud cracks, calcareous root	

Bed	Description	Thickness (meters)
	casts throughout; caliche horizons occur locally; locally well indurated and locally resistant................................	1.4
5	Siltstone; light olive gray, 5Y7/1 to pale yellowish brown 10YR6/2; very sandy to slightly argillaceous at top; basal contact is very sharp and irregular; lenticular-bedded, calcareous root casts and concretions occur throughout; well indurated but nonresistant................................	1.6
4	Siltstone; pale yellow brown, 10YR7/2; very sandy to argillaceous; basal contact is distinct; parallel laminated to lenticular-bedded, contains disarticulated fish fossils, subarkose lense of medium-grain size occurs in center; root casts and reticulate structure of sole surface of sand occur at base; friable and nonresistant................	3.8
3	Sandstone; grayish orange, 10YR7/4; subarkose consisting of coarse to very coarse-grained, spherical, subrounded, poorly sorted grains of quartz, orthoclase, mica; basal contact is distinct; interbedded with thin lense of siltstone; yellowish gray 5Y7/2; lenticular-bedded and contains limonitic concretions, fish fossils and calcareous root casts upward; unit grades to siltstone upward; loose and nonresistant..	2.5
2	Sandstone; moderate yellowish brown, 10YR5/4; lithic subarkose containing very fine-grained, well rounded, very poorly sorted grains of quartz, feldspar, rock fragments; argillaceous; basal contact is gradual transition rapid; medium bedded but parallel laminations in lower portion; caliches occur locally; disarticulated fish fossils, molluscs and root casts occur throughout; well indurated but nonresistant..............................	1.2
1	Sandstone; moderate yellowish brown, 10YR5/4 to pale yellowish brown, 10YR7/2; lithic subarkose is coarse to medium-grained at	

Bed	Description	Thickness (meters)
	base grades to fine grain at top, well rounded, sorted; basal contact is covered; lower 0.2 m is ripple-laminated with Lambda Type 2; contains thin siltstone interbed that is lenticular-bedded; unit contains calcareous root casts that are numerous and pebble bands are scattered throughout; friable and nonresistant..................................	2.6

Galana Boi Beds

The gray diatomaceous siltstones which cap the Guomde Formation in the Ileret area, the Koobi Fora Formation in the Koobi Fora area and the Kubi Algi Formation in the Allia Bay area have been designated the Galana Boi beds (Bowen and Vondra, 1973). Although the lithology and stratigraphic position of the widely distributed strata assigned to this unit are similar their exact lateral relationships are not yet fully known, thus the nomenclature has been kept informal.

The Galana Boi beds, which have been dated 9360 ± 135 BP at one locality in the Ileret area, occur as a thin (<0.15 meters) discontinuous mantle over most of the older sediments within a 2 to 4 kilometer wide band along the present lake shore. Locally the strata thicken to as much as 32 meters at Koobi Fora and occur in isolated outcrops up to 18 kilometers inland in the Allia Bay area. They are for the most part, horizontal and not faulted but in at least one instance they have been faulted to 120 inches above the present lake shore and occur in a cul-de-sac in the Kokoi horst complex.

Artifacts, algal stromatolites, gastropods (Melanoides) and Etheria banks (Fig. 17) are common in this sequence of yellowish gray

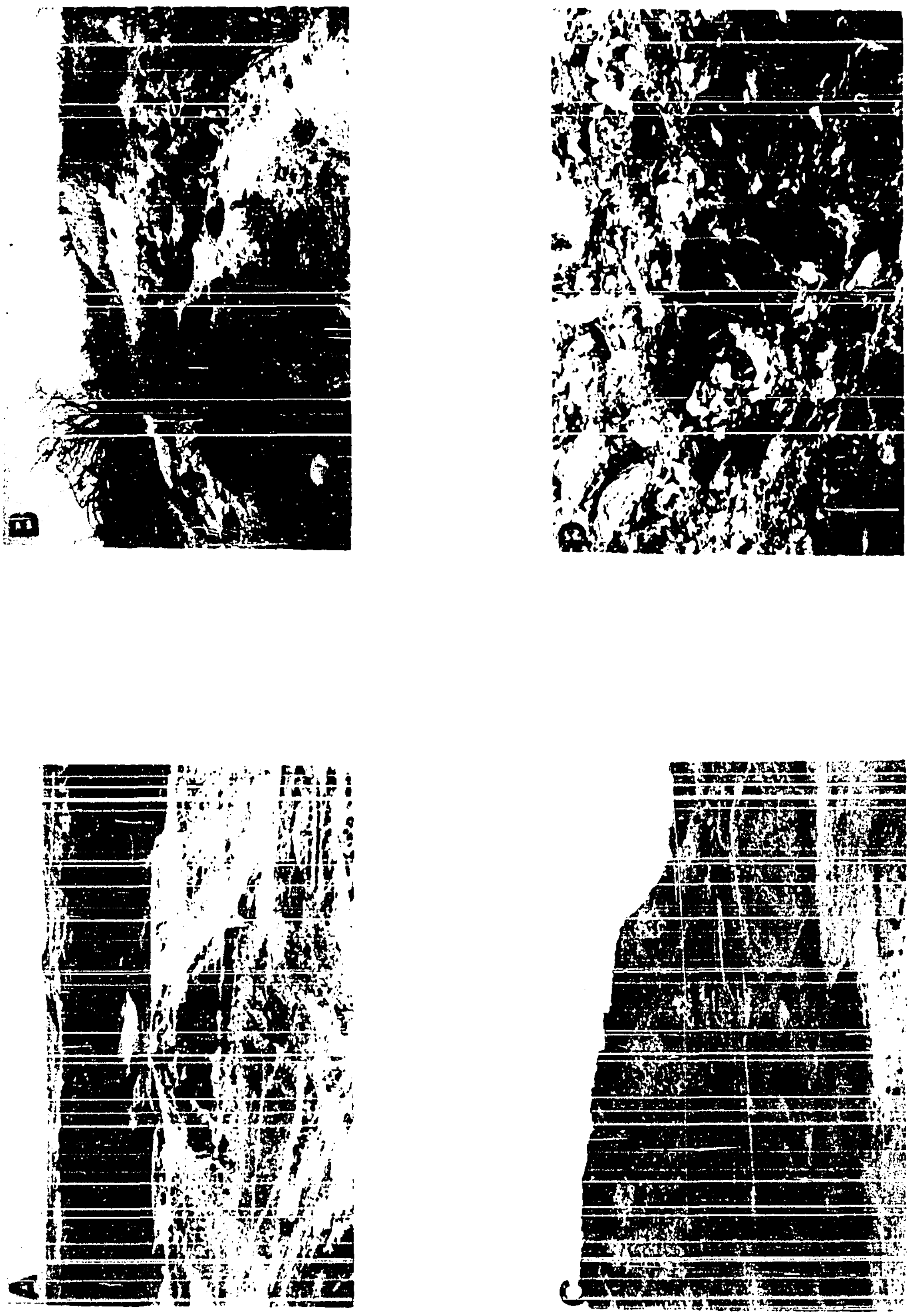
Fig. 17. Photographs of the Galana Boi beds

a. Exposure of Galana Boi beds overlying Koobi Fora Formation near Koobi Fora spit

b. Algal spheroids occur in Galana Boi beds at Ileret

c. Banks of <u>Etheria</u> are common

d. <u>Etheria</u> in the Galana Boi beds



(5Y7/2) parallel laminated, diatomaceous siltstones, tuffaceous mudstones and calcareous, trough cross-bedded to ripple-laminated, coarse-grained subarkoses. The units are thin, highly lenticular and grade vertically and laterally into each other.

PETROLOGY

The late Cenozoic sediments in the northeastern part of the Lake Rudolf basin consists of a varying mixture of conglomerate, sandstone, siltstone, claystone, carbonate and tuff units. All display a high degree of variability in thickness, composition, color and topographic expression.

Conglomerates

Extraformational conglomerates as well as intraformational types are contained in the Upper Cenozoic sediments of the East Rudolf embayment. Extraformational types are represented by three distinct suites. These are:

(1) Polymictic conglomerates, which occur mainly in the Ileret area and consist of quartz, orthoclase, metamorphic and plutonic igneous rock fragments and microcline in a coarse-grained arkose matrix usually cemented by calcite. The coarse clasts are moderately well sorted and well rounded granule to pebble-sized disc and spherical shaped particles. These conglomerates relatively localized and thus do not constitute a large volume of the sediments. They range from 0.2 to 6 meters in thickness.

(2) Polymictic conglomerates, which occur along and to the east of the Karari escarpment, west of Shin and along the Koobi Fora ridge. These conglomerates consist predominately of volcanic (basalt, ignimbrite), metamorphic (gneiss, schist, quartzite), plutonic igneous (granite) rock clasts in a coarse-grained sublitharenite matrix.

The gravel clasts are well-rounded, roller to subspherical granule to cobble-sized particles. A bimodal distribution of clast diameters is exhibited by these conglomerates. The size of the volcanic clasts tend to be one and one-half to three times larger than the plutonic igneous and metamorphic rock clasts. This difference decreases toward the center of basin.

(3) Oligomictic conglomerates, occurring in the Allia Bay area or along the eastern margin of the basin, consist either of basalt, rhyolite or ignimbrite fragments in a matrix of clay and/or coarse-grained sublitharenite cemented by iron oxide or calcite. The clasts are generally well-sorted, well-rounded, subspherical cobble to boulder-sized particles.

Intraformational conglomerates although relatively common do not constitute a large volume of the sediments. They occur as thin lenticular sheets of angular to well-rounded limonite clasts in a very calcareous fine-grained sublitharenite matrix. The clasts are derived from plate-shaped limonite nodules which occur in the underlying siltstones. They range from granule to cobble-sized particles.

Sandstones

Composition

Sandstones vary in composition laterally as well as vertically. In the Ileret area they vary from lithic arkose (27% quartz, 17% orthoclase, 8% microcline, 6% plagioclase, 26% rock fragments, 14% heavy minerals and 2% chert) near the margin of the basin to arkose

(33% quartz, 26% orthoclase, 10% microcline, 11% plagioclase, 9% rock fragments, 9% heavy minerals and 2% chert) toward the center of the basin. Vertically, quartz content increases to 46% while plagioclase and rock fragments decrease to 4% and 2% respectively and orthoclase, microcline, heavy minerals and chert remain essentially unchanged at 26%, 12%, 8% and 2% respectively (Fig. 18). Rock fragments constitute an increasing amount of the ferrigenous grains southward along the margin of the basin toward the Koobi Fora area. Consequently the sandstones there become feldspathic litharenites (21% quartz, 13% orthoclase, 8% plagioclase, 56% rock fragments, 3% heavy minerals and 5% chert). Vertically and toward the center of the basin the composition changes progressively to arkose (31% quartz, 17% orthoclase, 7% microcline, 27% plagioclase, 6% rock fragments, 13% heavy minerals and 2% chert) (Fig. 18).

The quartz grains of the sandstones generally display strong undulose extinction (>5%) with less than one per cent exhibiting straight extinction (<1%) suggesting that most are of a plutonic igneous or metamorphic rather than volcanic origin. Internal features of the quartz grains include vacuoles, bubble trains and microlites. Etching by calcite is common throughout the sedimentary sequence but silica overgrowths are common only in the sandstones which occur in the upper portions of the sequence. Quartz particles range from predominantly subangular to a few well rounded, spherical grains. Metaquartz, in the form of semicomposite and composite grains with intragranular units separated by sutured boundaries and displaying separate, strongly

Fig. 18. Percentages of mineralogical components of the sandstones

SAMPLE NUMBER	QUARTZ: Straight - slightly	QUARTZ: Strongly Undulose	QUARTZ: Semi-composite	QUARTZ: Composite	FELDSPAR: K. Feldspar	FELDSPAR: Microcline	FELDSPAR: Plagioclase	ROCK FRAGMENT: Metamorphic	ROCK FRAGMENT: Volcanic	ROCK FRAGMENT: Sedimentary	ROCK FRAGMENT: Plutonic Igneous	MATRIX: Carbonate	MATRIX: Clay	MATRIX: Fe-oxides	MISC.: Amphibole	MISC.: Biotite	MISC.: Opaques
ER-70-007-0109A	1	17	1	2	20	7	7	2	--	1	1	10	--	T	5	3	T
-0109C	4	26	5	2	16	12	9	1	1	--	--	12	--	T	6	2	14
-002-0118B	6	15	4	11	21	8	20	2	2	--	4	8	T	T	--	--	1
-0122	2	17	8	8	29	11	15	2	2	1	4	30	T	T	11	--	1
-003-0102	22	12	2	3	20	1	14	3	--	--	--	10	--	T	3	13	10
-006-0101B	1	14	3	9	21	9	10	3	8	2	4	17	--	2	14	1	1
-0108	5	16	2	3	13	5	20	1	2	--	1	85	--	1	12	1	17
-010-0106D	16	7	2	1	31	6	8	1	3	--	--	21	--	T	6	6	16
-0106C	3	3	11	16	14	5	19	6	6	1	17	10	--	2	1	--	1
-0106B	8	14	1	--	16	6	23	--	5	--	3	13	--	T	6	13	6
-0105A	3	22	3	3	19	3	14	3	1	--	1	78	--	T	10	7	16
-0104C	12	18	4	3	18	7	6	1	5	--	1	70	--	T	16	2	7
-0103D	7	20	15	3	9	15	3	2	9	--	1	12	--	T	2	3	5
-0102	1	21	10	--	31	2	16	--	6	2	--	6	--	T	5	4	--
ER-71-012-0135	8	5	11	6	15	5	7	3	14	3	8	26	--	T	1	4	9
-0130	--	15	2	--	16	8	8	10	15	7	8	3	10	T	6	1	4
-0121G	--	26	--	--	15	--	2	--	7	--	--	82	--	5	2	14	18
ER-71-104-0125	8	16	2	2	19	4	29	2	1	2	4	18	--	T	3	3	5
-031-0107	4	10	4	2	27	7	20	4	1	--	4	3	25	T	8	2	9
-103-0119	6	20	3	2	17	7	27	2	1	--	3	21	--	T	5	4	4
-031-0106	--	24	1	--	21	5	19	5	7	--	8	21	--	T	6	1	2
-030-0126A	2	12	4	3	12	1	8	3	48	--	5	30	5	T	2	1	--
ER-70-005-0106	2	36	3	5	26	12	4	--	--	2	--	18	--	T	6	2	--
-001-0112	3	33	8	2	23	14	2	1	--	3	--	15	2	T	3	--	1
-0110	2	38	10	1	21	10	4	1	--	1	5	21	3	T	4	1	2
-0107	2	40	12	8	20	8	--	2	--	2	1	10	10	T	2	--	3
-0104	2	38	12	6	28	12	--	--	--	2	--	12	--	T	--	--	--
-002-0105	5	35	2	1	39	16	2	--	--	--	--	10	--	T	--	--	--
-0113	7	36	4	2	28	12	3	--	--	2	--	8	2	T	6	2	--
ER-71-101-0102	5	21	3	2	17	7	26	--	--	6	2	T	13	T	4	--	9
-0106	2	29	--	--	19	5	28	--	--	4	3	14	3	T	3	--	11
-102-0140	7	30	5	4	15	4	25	3	--	5	2	11	--	--	2	--	4
-0136	2	36	3	2	21	5	29	--	4	5	--	17	--	T	3	--	6
-0111	7	27	4	5	17	2	4										
ER-71-030-0105	10	11	--	--	21	--	8	20	15	5	13	21	--	T	3	--	--
-0134	6	15			13	--	8	--	56	5	--	17	--	T	3	--	--
-0128	7	11	--	--	10	4	6	2	54	4	2	26	2	4	--	--	--
-0118	5	20	--	--	19	2	3	4	37	2	5	23	--	T	1	--	2

undulose extinction, comprises up to 16% of the quartz in the sandstones.

The feldspar content of the sandstones along the margin of the basin decreases toward the south from 31% in the Ileret area to 21% in the Koobi Fora area. Toward the center of the basin feldspar increases to about 50% of the framework grains for both areas. Grains of orthoclase generally appear fresh and unweathered while grains of microcline generally exhibit sericite alteration. Although sanidine was noted it was not differentiated from orthoclase because of the difficulty of obtaining the proper interference figure needed to calculate an accurate 2V. Therefore sanidine may constitute a small percentage of the orthoclase. Extinction angles of albite twin planes in plagioclase grains indicate compositions ranging from sodic to calcic with the calcic (laboradorite) being predominate. The amount of plagioclase in the sandstones increases southward from Ileret indicating the increasing influence of an extrusive volcanic source terrane. The amount of plagioclase also increases toward the center of the basin in both areas reflecting destruction of the volcanic rock fragments and decreases vertically suggesting the influence of weathering and recycling.

Rock fragments were tabulated as volcanic, (basalts, ignimbrites), plutonic igneous and metamorphic, and sedimentary rock fragments. The amount of volcanic rock fragments in the sandstones increases from the Ileret area south to the Koobi Fora area. Toward the center of the basin and vertically the amount of volcanic rock fragments decreases to about 2% of the terrigenous grains. The metamorphic and plutonic igneous rock fragments and sedimentary rock fragments tend to increase vertically and toward the basin center. The rock fragments range from medium to coarse-grained and are generally well rounded and spherical.

Accessory minerals include species derived from plutonic igneous, metamorphic and volcanic source terranes. Individual mineral varieties were identified by using the petrographic microscopic. Point counts of 100 grains were made to determine the relative abundance of each variety (Fig. 19). Mineral varieties and relative percentages fluctuate laterally, decreasing in metamorphic and plutonic igneous varieties and percentages southward from Ileret. The more stable accessory minerals increase vertically in relative abundance in both areas.

The accessory minerals range in grain size from coarse silt to medium sand. Near the margin of the basin they are angular to subrounded and show relatively little etching or alteration. Vertically and toward the center of the basin the accessory minerals show a reduction in average grain size and increased rounding, etching and alteration.

Montmorillonite, chlorite and mixed-layer montmorillonite-illite clays are frequently important constituents in the clay-size fraction of the sandstones. They usually constitute about 4% by weight but may comprise as much as 23%. The clay fraction is usually evenly distributed throughout the sandstones.

Calcite is the major cementing agent of the sandstones and may comprise up to 50% of the rock. In the more friable sandstones the sparry crystal of calcite occur as scattered patches while in the indurated sandstones they form an interlocking mosaic within a disrupted

Fig. 19. Relative percentages of heavy minerals

Sample Number	Opaques: Magnetite	Opaques: Hematite	Opaques: Leucoxene	Nonopaques, Volcanic: Oxyhornblende	Nonopaques, Volcanic: Hypersthene	Nonopaques, Volcanic: Olivine	Nonopaques, Volcanic: Serpentine	Nonopaques, Nonvolcanic: Hornblende	Nonopaques, Nonvolcanic: Apatite	Nonopaques, Nonvolcanic: Rutile	Nonopaques, Nonvolcanic: Tourmaline
ER-70-010-0104	9	--	--	43	--	5	--	33	--	1	--
-006-0108	10	--	--	55	5	15	--	5	--	10	--
ER-71-030-0126	17	2	4	55	2	15	--	9	2	3	1
-105-0210	15	--	20	59	--	--	--	4	2	--	--
-102-0146	14	--	29	57	--	--	--	--	--	3	3
-012-0116	20	--	7	41	--	17	--	4	--	3	3
-0135	1	2	5	55	2	19	--	5	2	4	5
-0131I	1	3	70	10	--	--	--	--	--	5	6
-0118	18	3	10	45	4	13	2	3	--	2	1
ER-70-002-0128	2	2	24	56	--	--	--	--	--	6	10
-003-0118	10	4	18	58	2	--	--	12	2	11	2
-004-0102	5	4	17	48	--	--	--	9	3	8	6
-005-0108	6	2	12	52	2	--	--	10	4	5	6
-007-0107A	10	2	13	44	--	--	--	13	3	7	4
ER-71-105-0105	5	3	5	48	2	--	--	22	5	6	4
-102-0110	6	--	4	53	2	--	--	25	--	3	1
- -0122	5	2	12	43	--	--	--	33	--	4	1
-108-0102	3	1	8	48	3	9	2	18	3	7	1

granular framework. Iron oxide, silica and barite cement occur less commonly and generally comprise less than 1% of the rock.

The increasing amount of volcanic rock fragments and the decreasing amount and variety of plutonic igneous and metamorphic accessory minerals in the sandstones southward from Ileret may indicate differences in source area, distance of transport and environment of deposition. Precambrian plutonic igneous and metamorphic rocks which outcrop northeast of Ileret in Ethiopia near the northern limit of Lake Stephanie may have been the source of the plutonic igneous and metamorphic mineral suites in the Ileret area. The overabundance of volcanic rock fragments and volcanic mineral suites in the sandstones near Koobi Fora indicate the dominating influence of a local volcanic source. The relative depletion of plagioclase, the concentration of the more stable accessory minerals and the occurrence of some abraded quartz overgrowths and sedimentary rock fragments in the sandstones vertically and toward the center of the basin suggest reworked sediments as a minor source for the younger sandstones. The compositional immaturity of these sandstones may reflect the tectonic instability of the area and rapid deposition and burial as well as the general aridity of the depositional area at the time of deposition.

Texture

The sandstones range from very fine (3.98 ϕ) to coarse-grained (0.20ϕ). These have a mean diameter of 2.29ϕ (0.22 millimeter, fine sand) and a standard deviation of 0.88 ϕ units (Fig. 22). No regional effect in grain size distribution was noted. There is little difference

Fig. 20. Statistical measure values of selected sandstones

Sample	Phi Mean ($\bar{x}\ \emptyset$)	Phi Deviation ($\sigma\emptyset$)	Phi Skewness ($SK\emptyset$)	Phi Kurtosis ($K\emptyset$)
ER-70-003-0108A	3.98	2.52	0.53	0.81
-0110	3.23	2.41	0.42	2.73
-0114A	1.67	1.47	0.12	1.16
-0115	1.97	1.26	0.28	1.54
-0016	2.17	0.86	0.62	1.03
-0118	2.40	2.38	0.34	2.07
ER-70-004-0101A	2.17	1.06	0.14	1.32
-0101B	1.07	1.88	0.19	1.39
-0102	2.20	1.55	0.21	1.93
ER-70-007-0101B	3.32	1.46	0.02	1.43
-0101D	1.45	1.60	0.15	1.31
-0102A	3.56	2.29	0.58	1.07
-0102C	2.88	1.65	0.38	1.34
-0103B	2.86	1.45	0.39	1.14
-0103C	2.58	1.43	0.36	2.34
-0104	2.68	1.56	0.51	2.28
-0108A	2.52	1.22	0.21	0.76
-0108B	3.50	1.05	0.21	1.35
-0109A	3.37	1.45	0.22	2.09
-0109F	1.87	1.77	-0.08	2.26
ER-71-030-0102	1.37	2.56	0.43	1.12
-0105A	2.80	1.62	0.59	2.68
-0106A	1.40	1.16	0.47	2.25
-0118A	1.03	2.74	0.38	0.99
-0121B	2.90	1.02	-0.24	1.00
-0128	1.13	1.65	0.52	1.21
ER-71-031-0106	0.33	1.28	-0.14	1.23
-0108	1.15	0.94	-0.15	1.30
ER-71-108-0101B	1.97	0.76	-0.24	1.30
ER-71-012-0110	1.40	1.16	0.47	2.25
ER-70-103-0201A	0.43	1.39	0.28	1.64
-0231	0.30	0.79	0.09	1.19
ER-71-101-0108	1.77	1.00	0.08	1.30
-0119	0.27	2.01	0.38	1.93
ER-70-010-0101C	1.90	1.01	0.36	2.13
ER-71-105-0305	0.83	2.57	0.40	0.96
-0210	-4.03	2.10	0.28	1.56
ER-71-103-0120	-1.87	2.18	0.34	0.97
ER-71-102-0104	3.50	0.57	-0.21	1.43
-0111	-2.23	2.27	0.35	0.98
ER-71-012-0114	0.27	2.19	-0.41	1.37
ER-71-108-105A	3.12	0.48	0.03	1.01
-0112A	1.43	0.96	-0.29	1.01
ER-71-031-0104	2.57	1.01	0.14	1.64
-0107	2.78	1.96	0.43	0.79
-0112C	0.33	0.74	0.03	0.98
ER-71-030-0130	1.23	1.02	0.19	1.00
-0129C	2.50	0.59	-0.03	0.97
-0129A	3.77	1.25	-0.03	0.96
-0126B	2.12	1.03	0.53	2.90
-0124	1.98	0.77	-0.03	1.05
-0121J	2.13	1.45	-0.35	1.49
-0121I	3.00	1.46	-0.60	1.42
-0121H	1.77	1.11	0.24	1.10
-0121G	2.40	1.48	-0.32	0.98
-0121F	1.20	0.84	0.09	3.96
-0121E	2.60	1.06	-0.13	0.82
-0121D	2.80	1.23	-0.22	0.87
-0121C	1.47	0.86	-0.36	1.19
-0121A	3.50	0.52	-0.21	1.43
-0118C	1.03	2.74	0.38	0.99
-0106I	2.97	0.64	-0.06	0.96
-0106H	2.50	1.33	-0.31	1.23
-0106G	3.43	0.79	-0.22	1.07
-0106C	2.93	1.04	-0.15	0.82

$\bar{x}\emptyset = \frac{\sum fm}{n}$ $\sigma\emptyset = \left(\frac{\sum f(m-\bar{x}\emptyset)^2}{100}\right)^{\frac{1}{2}}$ $SK\emptyset = \frac{\sum f(m-\bar{x}\emptyset)^3}{100\sigma\emptyset^3}$ $K\emptyset = \frac{\sum f(m-\bar{x}\emptyset)^4}{100\sigma\emptyset^4}$

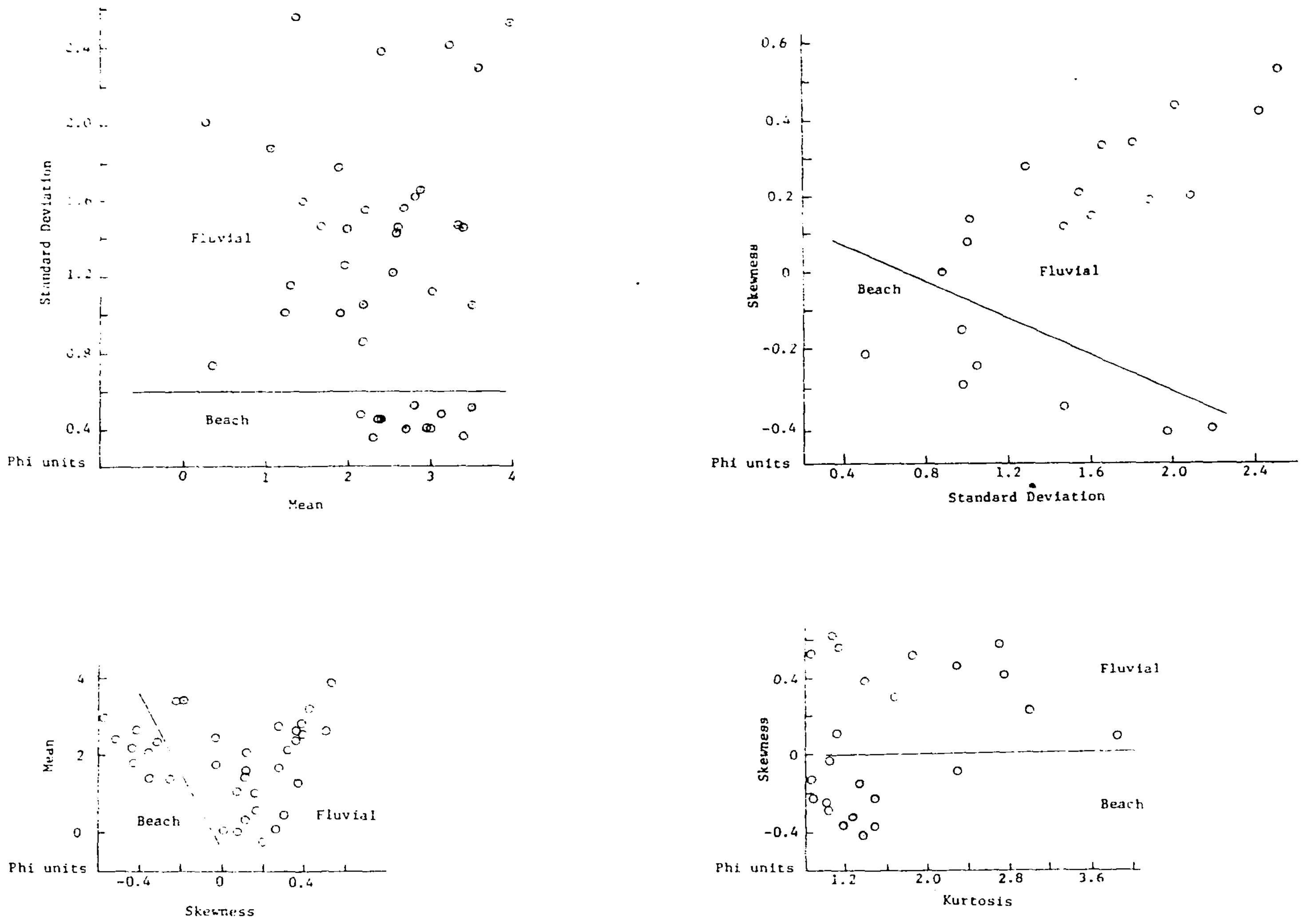
in the mean grain size among the three areas. Thus, grain size of a sandstone reflects the local depositional environment.

The average standard deviation of the sandstones is 1.42 ϕ (poorly sorted) with a range from 0.52 ϕ (moderately well sorted) to 2.74 ϕ (very poorly sorted). Some of the sandstones show a strong bimodal distribution of grain size reflecting the silt and clay content of the sandstones. Commonly the silt and clay-sized particles make up around 15% by weight of a given sandstone but frequently comprise as much as 50%.

The skewness and kurtosis values of the sandstones were also calculated. Skewness averages +0.13 (fine-skewed) and ranges from -0.60 to +0.85 with a standard deviation of 0.27. Average kurtosis is 1.68 (very leptokurtic) with a range from 0.61 to 4.92 and a standard deviation of 0.72. This would indicate that the central portion is better sorted than the extremes.

The statistical parameters indicate that the average sandstone is texturally immature. This is consistent with the interpretation that most of the sandstones were deposited in fluvial or fluvial-deltaic environments. The few sandstones that were deposited in environments where winnowing processes were more effective are easily distinguished from the fluvial sandstones on the basis of mean size versus standard deviation, skewness and kurtosis plots (Fig. 21).

Fig. 21. Statistical measure plots of selected sandstones



Interpreted from Folk (1968)

Mudstones

Mineralogy

Quartz and clay minerals are the dominant constituents of siltstones, claystones and mudstones. Montmorillonite is the most abundant clay mineral with chlorite, illite, mixed-layered montmorillonite, vermiculite and zeolites occurring in minor amounts. Little difference in clay composition was noted among beds of different color or from one area to another within the basin except that no illite was found in the sediments in the Koobi Fora area (Fig. 22).

Texture

Particle-size analysis of 51 siltstones and mudstones utilizing the pipette method (Folk, 1968) was conducted to gain an approximation of the percentage of clay-size material. The mean grain-size of the siltstones and mudstones is 5.43 ϕ (medium silt) and the average standard deviation is 2.17 ϕ (very poorly sorted). The clay-size content averaged about 18%.

A particle-size analysis of samples taken at 5 centimeter intervals from two vertical siltstone profiles identified in the field as possible paleosols was made in order to evaluate in situ modification. Free iron, aluminum and manganese were also determined at intervals of 5 centimeters to aid in the evaluation (Fig. 23). The samples show a vertical variation in 1 μ clay distribution, free manganese and aluminum. A slight variation is noted for free iron. The results indicate that these particular siltstones have undergone slight pedogenic modification.

Fig. 22. Typical x-ray diffractometer tracing for mudstones

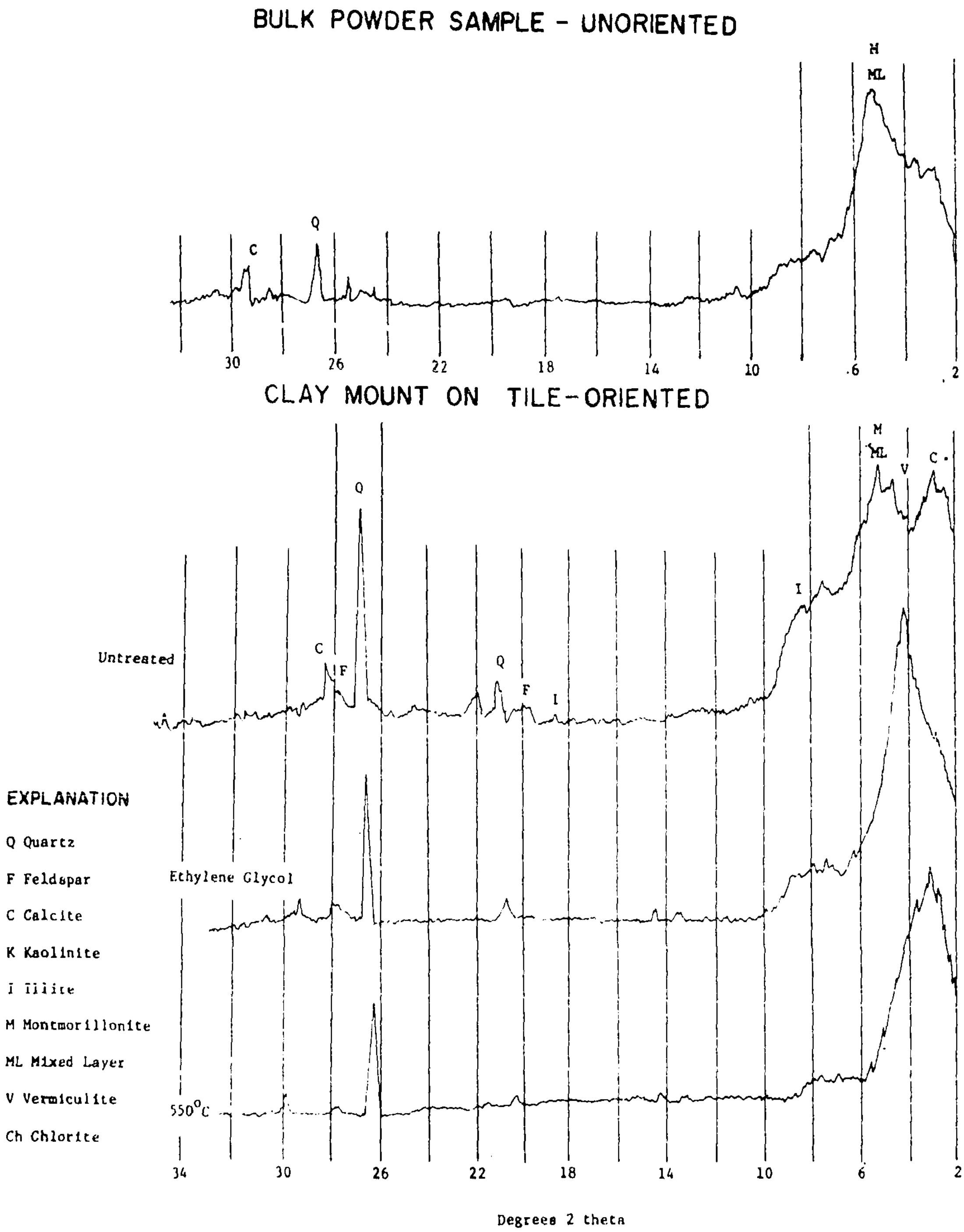
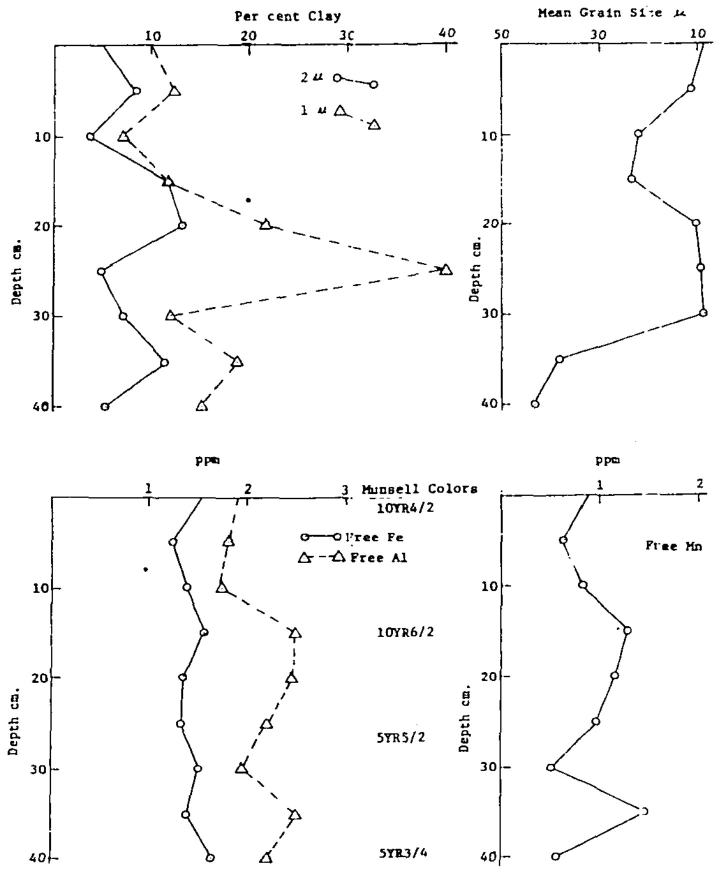
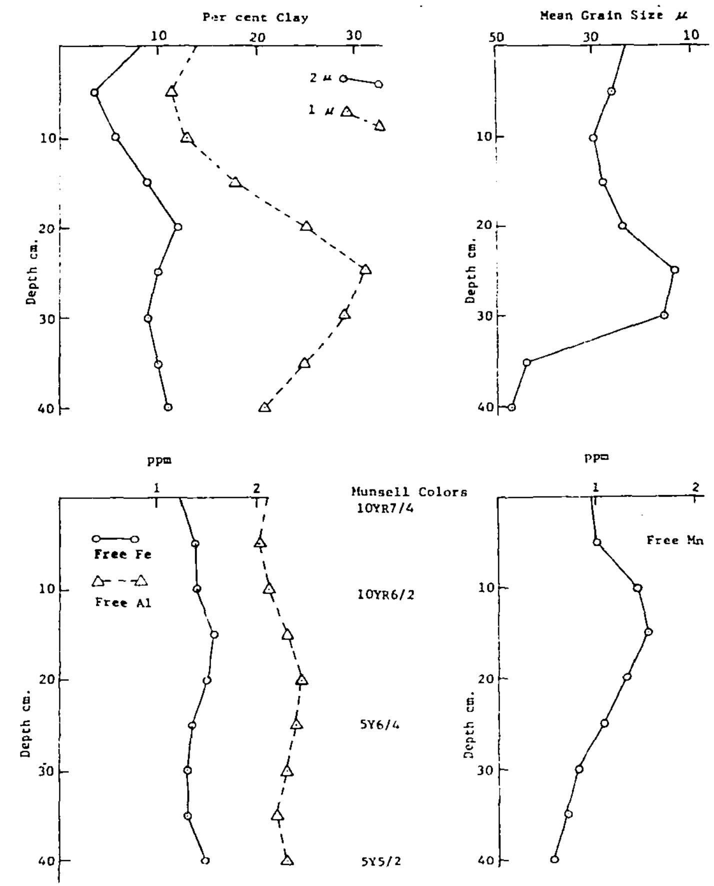

BULK POWDER SAMPLE - UNORIENTED
M
ML
C
Q
30
26
22
18
14
10
6
2
CLAY MOUNT ON TILE-ORIENTED
M
ML
V
C
Q
I
Untreated
C
F
Q
F
I
EXPLANATION
Q Quartz
F Feldspar
C Calcite
K Kaolinite
I Illite
M Montmorillonite
ML Mixed Layer
V Vermiculite
Ch Chlorite
Ethylene Glycol
550°C
34
30
26
22
18
14
10
6
2
Degrees 2 theta

Fig. 23. Vertical distribution of clay, mean grain size, free iron, aluminum and manganese in two siltstone sequences.



ER-71-012-0131



ER-70-004-0103

Carbonates

Carbonates of the Late Cenozoic sediments in the northeastern part of the Lake Rudolf basin are readily separated into three types: (1) biolithites, (2) arenaceous bioclastic carbonates and (3) arenaceous coarsely crystalline (.0625 - 2.0 millimeters) carbonates essentially devoid of fossils. The orthochemical component of these carbonates is predominantly calcite with minor amounts of rhombohedral dolomite. The dolomite is usually outlined by a ring of iron oxide and may exhibit up to three zones. The calcite occurs as crystals of around 10 microns or more in diameter between the allochemical components.

Gastropods (*Melanoides* sp., *Cleopatra* sp., *Mutela* sp.), pelecypods (*Corbicula* sp., *Nyassunio* sp.) (Vandamme and Gautier, 1972; Gautier and Vandamme, 1974) and ostracods comprise the allochemical component of the arenaceous bioclastic carbonates. These fossils occur either as whole and unabraded or as abraded disarticulated shell fragments comprising between 10 to 50% of the rock. The carbonates can be classified as biosparites, biosparudites, packed biosparites and packed biosparudites (Folk, 1968).

The biolithites exhibit algal stromatolite structures (Fig. 24). Grain-size ranges from 1 to 5 microns in the stromatolite structure. Larger crystal (10 to 20 microns) fill or partially fill the numerous pores.

Sparry crystals of calcite form an interlocking mosaic within the arenaceous, coarsely crystalline carbonates. These carbonates, which have a high terrigenous content, are disrupted framework sandstones.

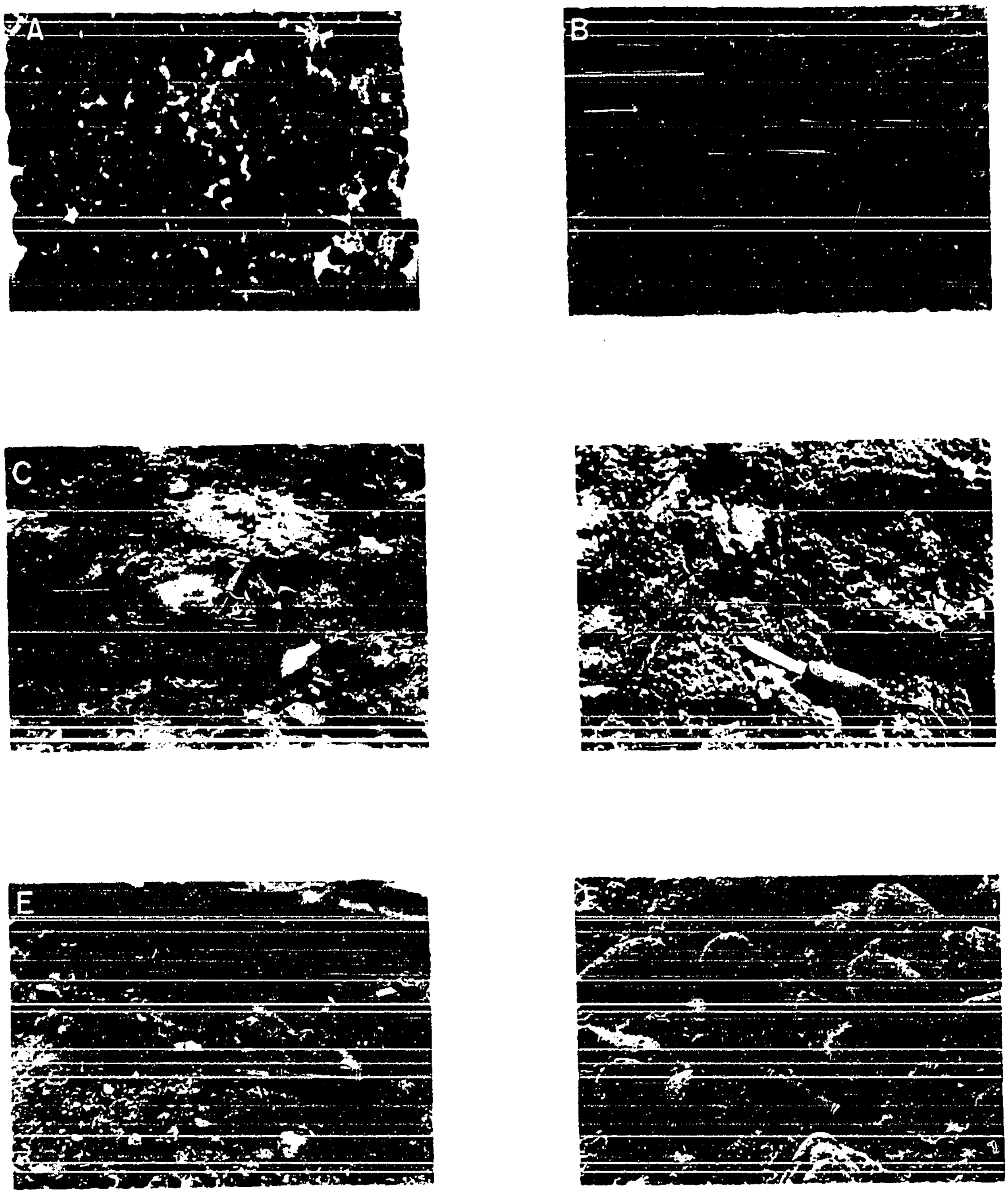
Fig. 24. Photographs of algal stromatolites

a. Thin-section

b-c. Mat showing concentric structures

d. Mudcracked algal mat

e-f. Spheroids are also common


A
B
C
E

They are classified as carbonates only because calcite comprises more than 50% of the rock.

Terrigenous component of the carbonates varies from clay-sized particles to coarse sand-sized particles and may comprise up to 50% of the rock. The particles consist of quartz, feldspar, hornblende, biotite, clay and a few rock fragments of various lithologies. Dissolution effects are slight although common distribution of the particles is random except in the arenaceous coarsely crystalline carbonates. In these carbonates the terrigenous component varies vertically from 50% at the base to 10% or less near the top of a unit.

Tuffs

The tuffs consist of glass shards, sanidine, hornblende, biotite, quartz and pumice fragments. Some locally contain a significant amount of terrigenous material, authigenic montmorillonite clay and secondary calcite. Considerable variation in texture and degree of alteration is evident within the same tuff as well as from one tuff to another. The glass shards, which show alteration rims, range in diameter from 250 microns to less than 2 microns but average around 95 microns (very fine sand). They range from very angular and delicate elongate shards to well rounded and spherical. Index of refraction varies from 1.442 to 1.510 for most of the shards. The primary minerals are highly angular and usually in the same size range or slightly smaller than the associated shards. Pumice fragments are locally abundant. They vary in diameter from 1 to as much as 450 millimeters and are well rounded spherical to roller shaped particles. They often contain a considerable amount of secondary calcite.

FACIES AND ENVIRONMENTS OF DEPOSITION

Four major lithofacies, each consisting of many microfacies have been recognized in the Upper Cenozoic sediments in the East Rudolf embayment. These are (1) the laminated siltstone facies; (2) the arenaceous bioclastic carbonate facies; (3) the lenticular fine-grained sandstone and lenticular-bedded siltstone facies; and (4) the intertongued lenticular conglomerate, sandstone and mudstone facies (Vondra and Bowen, in press 1974). These possess properties indicative of four major depositional environments (1) prodelta and shallow shelf lacustrine; (2) littoral lacustrine--beach and barrier beach and associated barrier and supralittoral lagoons; (3) delta plain--distributary channel and interdistributary flood basin; and (4) fluvial channel and flood plain (Vondra and Bowen, in press 1974).

The facies are complexly interbedded and intertongued. Their position at any given time was related to the level of the lake which in turn was controlled by variations in climate and tectonic activity. In general the four major facies occur on north-south trending belts which migrate to the west during the late Cenozoic recording a general regression of the lake. A preliminary examination of the facies and environments of deposition represented by the Upper Cenozoic sediments in the East Rudolf embayment has been presented by Vondra and Bowen (1974, in press) and the following discussion is based on and expanded from that presentation. Thus no further reference will be made to that paper.

Laminated Siltstone Facies

The laminated siltstone facies is aerially distributed in a lobe extending out from the basin margin slightly northeast of Koobi Fora. It is exposed along the base of the Koobi Fora ridge and along stream cuts to the west of Shin. Here the facies constitutes nearly all of the Lower Member of the Koobi Fora Formation. It interfingers laterally with and grades vertically into the arenaceous bioclastic carbonate facies to the east and north along the basin margin and south and west toward the mouth of Laga Bura Hasuma.

The stratigraphic occurrence of the laminated siltstone facies is unique. Occurring 2 to 3 meters above the Tulu Bor Tuff near the eastern end of the Karari escarpment the facies thickens from 5 meters to 42 meters near Koobi Fora spit. Here it immediately overlies the Tulu Bor Tuff and continues to 4 meters above the KBS Tuff.

The facies consists of sequences of thin bedded to parallel laminated, yellowish gray (5Y7/2), limonitic, argillaceous siltstones near the the eastern end of the Karari escarpment. Toward the present lake margin this sequence acquires increasingly more interbeds of thin, laminated, grayish orange (10YR7/4), feldspathic litharenites; thin, grayish orange (10YR7/4), packed molluscan biosparudites; and laminated, light gray (N-7), bentonitic tuffs. The siltstones contain thin lenses of sandstone and conglomerates consisting of pebbles of bioclastic carbonates. Thin plate-shaped, limonite nodules, parallel to laminae, and subvertical to horizontal veins of selenite, generally less than 5 millimeters in thickness are common.

The laminated siltstones generally occur in units between 2 and 4 meters thick, although units as thick as 18 meters have been found in exposures at Koobi Fora near the present lake margin. Their basal contacts are usually sharp but non-erosional while their upper boundaries are gradational. Individual units as well as the entire sequence tends to coarsen upward to argillaceous sandstones capped by packed molluscan biosparudites. These sandstones are ripple-laminated and occasionally bioturbated. Fossils in this facies are rare when compared with other facies with which they are interfingered. They usually consist of scattered small lenses of whole, unabraded, lacustrine gastropods (Cleopatra sp., Melanoides sp.) in the siltstones and as broken and abraded molluscan fragments in the thin biosparudites.

The fine-grained nature and lamination of the siltstones indicate deposition under low energy conditions with the upward coarsening, ripple-laminated sequence suggesting periodic current activity. This along with the sporadic occurrence of gastropods, the distribution and geometry of the facies and its relationship to interfingering facies suggest that the facies was deposited in a proximal prodelta or delta shelf environment (Donaldson et al., 1970; Allen, 1965). The stratigraphic position of the large concentration of plate-shaped limonite concretions in the center of the upward coarsening units suggest that parts of this facies were deposited very near shore. Recent limonite concretions of this type have been noted by the writer to occur just below the surface near the base of the root zone of reeds (Phragmites sp.) growing along the shore line of the Tulu Bor delta near Ileret.

This phenomenon has been attributed to a change in oxidation-reduction potentials associated with flooded soils (Black, 1968). The thin layers of brown hydrous iron oxide mark the level where the oxidation-reduction potential is above 0.3 volts or high enough to oxidize ferrous iron moving up from beneath. The occurrence of arenaceous bioclastic carbonates at the top of each unit tends to lend further support to the suggestion that the units of the laminated siltstone facies represent increasingly shallow environments or a regressive sequence from prodelta to shallow shelf lacustrine to barrier beach environments (Fig. 25).

Arenaceous Bioclastic Carbonate Facies

The geographic extent of this facies is difficult to define because it is so intimately interbedded with other facies. It is exposed throughout the basin and occurs intermittently in the entire Upper Cenozoic sedimentary sequence. Eastward it interfingers with and vertically passes into the lenticular fine-grained sandstone and flaser-bedded siltstone facies.

Lithologically near Koobi Fora spit the facies consists of very sandy, dark yellowish orange (10YR6/6) to moderate yellowish brown (10YR5/4), packed gastropod and/or ostracod biosparudite which may grade laterally into dark yellowish brown (10YR4/2) to yellowish gray (5Y7/2) very calcareous and fossiliferous, fine to medium-grained, lithic subarkose or into grayish orange (10YR7/4), biolithites possessing algal stromatolite structure. Individual beds vary in thickness from 5 centimeters to 3 meters and all diminish in thickness and pinch

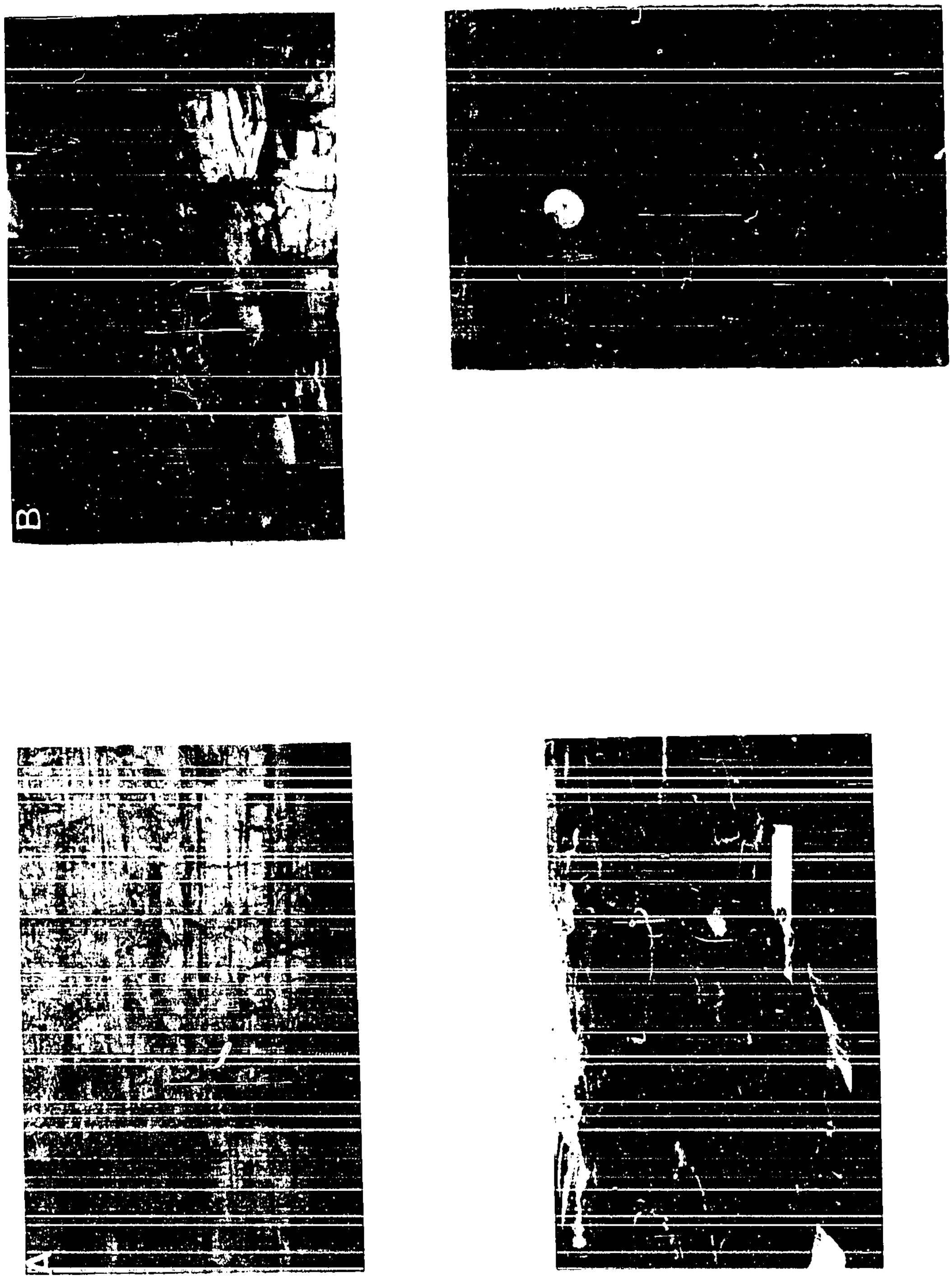
Fig. 25. Photographs of laminated siltstone facies

a. Typical exposure showing parallel laminated siltstones and fine-grained sandstones

b. Limonite concretions occur along bedding planes

c. Plate-shaped limonite concretions showing algal growth surrounding concretion

d. Parallel laminated tuffs showing slump features


B
A

out to the east. Vertically they display a distinct sequence of primary structures. The basal portion of each unit is a laminated silty, fine-grained sandstone which is gradational with the underlying laminated siltstone. It contains vertical burrows and occasional internal molds of the bivalve Mutela. This becomes a ripple-laminated and trough and planar cross-bedded fine to medium-grained very calcareous sandstone or arenaceous bioclastic carbonate in the middle portion and a fine-grained sandstone which is structureless with the exception of occasional root casts and ripple-marks in the upper portion (Fig. 26).

The upper half of the middle portion is often packed with the shells of gastropods (Bellamya sp.) and/or ostracods. Disarticulated fish remains, fragments of algal mats or spheroids, occasional fragments of, as well as, complete bivalves and relatively rare abraded mammalian bones may also occur. Laterally, as well as vertically, this sometimes gives way to thin algal biolithites which locally display three basic geometric forms of stromatolite growth-mats, hemispheroids and spheroids (Fig. 25) (Johnson, 1974). Oncolites or concentrically stacked spheroids (SS-C) (Logan et al., 1964), domes or vertically stacked hemispheroids (SH-V) (Logan et al., 1964) and inverted stacked hemispheroids (SH-I) (Kendall and Skipwith, 1968) are common forms (Johnson, 1974). Although forms described by Kendall and Skipwith (1968), such as the forms of the cinder and polygon zones were noted, no attempt was made to relate them to any lateral sequences of environments.

Near Koobi Fora spit the carbonates and sandstones of this facies are often associated with 1 to 2 meter beds of massive, pale yellowish

Fig. 26. Photographs of arenaceous bioclastic carbonate facies

a. Outcrop of an arenaceous bioclastic carbonate interpreted as representing a barrier beach

b-e. Photographs illustrating typical sequence of primary structures in a barrier beach sequence from occurrence of <u>Mutela</u> at the base (b) to ripple laminations (d) and algal mats (e) at the top.


A
B
D
E

brown (10YR6/2) siltstone. It has a gradational lower contact and is sandy at the base becoming very argillaceous at the top. The siltstone contains calcareous concretions, calcareous root casts and thin subvertical veins of gypsum. An occasional thin limonite clast, pebble or cobble intraformational conglomerate with a very sharp and erosional lower boundary is intercalated with these siltstones.

At Ileret this facies consists of a series of 3 centimeter to 4 meter thick pale yellowish brown (10YR6/2) very fine to very coarse-grained lithic subarkoses capped by thin (3 centimeters to 10 centimeters), dark yellowish brown (10YR2/2), packed gastropod biosparudites. Occasionally the biosparudites thicken laterally to 1.5 meters and contain mud cracks at the base. Claystones and siltstones are rare in this sequence. They are generally moderate yellowish brown (10YR5/4) or pale yellowish brown (10YR6/2) and grade vertically from thin bedded to massive. Vertically they are very sandy and extensively bioturbated.

The loose to friable, poorly sorted lenticular sandstones show indistinct low angle small-scale planar cross-beds. Their lower boundaries are usually gradational. They contain mud cracks, load casts, calcareous root casts and numerous vertebrate fossils. Although they do tend to become coarser-grained vertically, there is no detectable sequence of primary structures. Algal stromatolites are conspicuously absent.

Studies of recent shallow marine deposits and recent littoral deposits of Lake Rudolf indicate the geometry and sequence of sedimentary structures which occur in coastal interdeltaic sediments are similar to those of the arenaceous bioclastic carbonate facies (LeBlanc, 1972). The three distinct units of sandstones, bioclastic carbonates and siltstones of this facies at Koobi Fora spit correspond in texture and structural features to the sediments accumulating as shore face, beach and sand dune environments described by various authors (Dickinson et al., 1972; Davis et al., 1971 and Weide, 1968) and as observed by the writer for barrier beaches at Lake Rudolf. These units were deposited by shoreward migrating submergent bars or megaripples as barrier beaches while the massive siltstone accumulated in low energy lagoons behind the barriers. Algal stromatolites formed in associated very shallow water littoral or supralittoral lagoon environments.

The sequence at Ileret may have been deposited in a similar manner although its characteristics are not distinguishable from those attributed to the chenier plain (Byrne et al., 1959; Gould and McFarlan, 1959 and Hoyt, 1969). The major difference between cheniers and barrier beaches is the sequence of development. The sand ridge which forms the chenier is preceded by extensive mud flat development where as in the development of the barrier the elongate sand body is formed first and protects a lagoon where muds accumulate (Hoyt, 1969). The basic difference in the depositional conditions of cheniers and barriers is the proximity of a major sediment source capable of overloading the distributive agencies along the adjacent shore line. Near such a source there may be an alternation of progradation and erosion and the development of cheniers. With a smaller influx of sediment, sorting is accomplished more readily and sand accumulates as a barrier along the shore line.

Cheniers tend to be thinner, narrower and less extensive than barriers. Barriers tend to have abundant high angle stratification while cheniers typically consist of gently dipping deposits with numerous wash over fans and thin dune accumulations (Byrne et al., 1959 and Hoyt, 1969).

The tuffs are relatively thick (up to 4 meters) and may be locally extensive in this facies. They overlie either sandstones or siltstones and have gradational to very sharp lower boundaries. The tuff units that have a gradational lower boundary generally show the same bedding features at the base as the underlying unit. Ripple-laminations are common and locally the tuffs may be small-scale trough cross-bedded but the dominant bedding type is parallel laminations. Locally they contain rounded pumice cobbles up to 30 centimeters in diameter, fine to coarse-grained sand and locally they are very argillaceous. Root casts often occur throughout the tuff units as well as in capping caliche horizons and artifacts and vertebrate fossils occur locally.

Lenticular Fine-Grained Sandstone and Lenticular-Bedded Siltstone Facies

This facies occurs throughout the basin and comprises the greatest volume of all the facies. It constitutes most of the upper portion of the Kubi Algi Formation and the basal and uppermost portions of the Guomde Formation. In the Koobi Fora Formation the base of the lenticular fine-grained sandstone and lenticular-bedded siltstone facies climbs stratigraphically from about 30 meters below the Tulu Bor Tuff along the margin of the basin near the Karari escarpment to well above the KBS Tuff near Koobi Fora spit. In the Ileret area this facies constitutes almost all of the Ileret Member and about half of the Lower Member and is complexly intertongued with the arenaceous bioclastic carbonate facies from the Suregei Tuff Complex up to the KBS Tuff along the margin of the basin. The lenticular fine-grained sandstone and lenticular-bedded siltstone facies usually overlies the arenaceous bioclastic carbonate facies but locally it rests unconformably on the laminated siltstone facies. It interfingers laterally with the lenticular conglomerate, sandstone and mudstone facies.

The facies consists of 1 to 25 meter thick lenticular channels of grayish orange (10YR7/4) fine to medium-grained sandstone which grade into or interfinger with 1 to 2 meter thick, pale yellowish brown (10YR6/2), lenticular-bedded, coarse-grained siltstone. Occasionally a thin, dark yellowish orange (10YR6/6) limonite clast intraformational conglomerate or a thin lenticular ripple-laminated to parallel laminated, light gray (N-7) tuff interrupts this sequence. The sandstone bodies usually grade upward in grain size from the underlying siltstones and are predominately small-scale cross-bedded (Nu) but often locally display a sequence of structural features ranging upwards from pebble conglomerates through large-scale trough (Pi) and planar cross-bedding (Alpha) to scale-scale trough (Nu) and horizontal bedding. These features are grouped into sets usually no more than 15 centimeters thick and may be capped with a thin argillaceous silt drape. Pebble lenses with clay galls, distorted bedding, slump structures, sand volcanoes, load casts and mud cracks are common. Convolute laminations occur less frequently in the silty sandstones. A sequence of primary structures was noted in these sandstone units. The basal portion of these sandstones display ripple-drift cross-laminations in which both grain-size and ripple amplitude increase upward. The laminations of the uppermost ripple are usually disturbed and overturned. This is followed by distorted bedding which is occasionally truncated by thin parallel silt laminae. Locally root casts are very abundant in the sandstones and occasionally they are capped by lenses of Etheria.

The thin, pale yellowish brown (10YR6/2) siltstones are very sandy and contain thin (1 to 3 centimeters) horizontal to subhorizontal lenses of fine-grained sandstone which extend laterally 1 to 10 centimeters before pinching out. Adjacent to the channel the siltstones contain thin (3 to 10 centimeters) intercalations of poorly sorted conglomerates and coarse-grained sandstones. The siltstones become progressively more fine-grained and more argillaceous laterally with respect to the axis of the channel. They contain limonite concretions or laminae near the base, abundant mud cracks throughout, 10 centimeter thick lenses of claystone locally and numerous calcareous root casts associated with capping caliche horizons. Slightly abraded and disarticulated vertebrate fossils are common but articulated fossils do occasionally occur in this facies (Fig. 27).

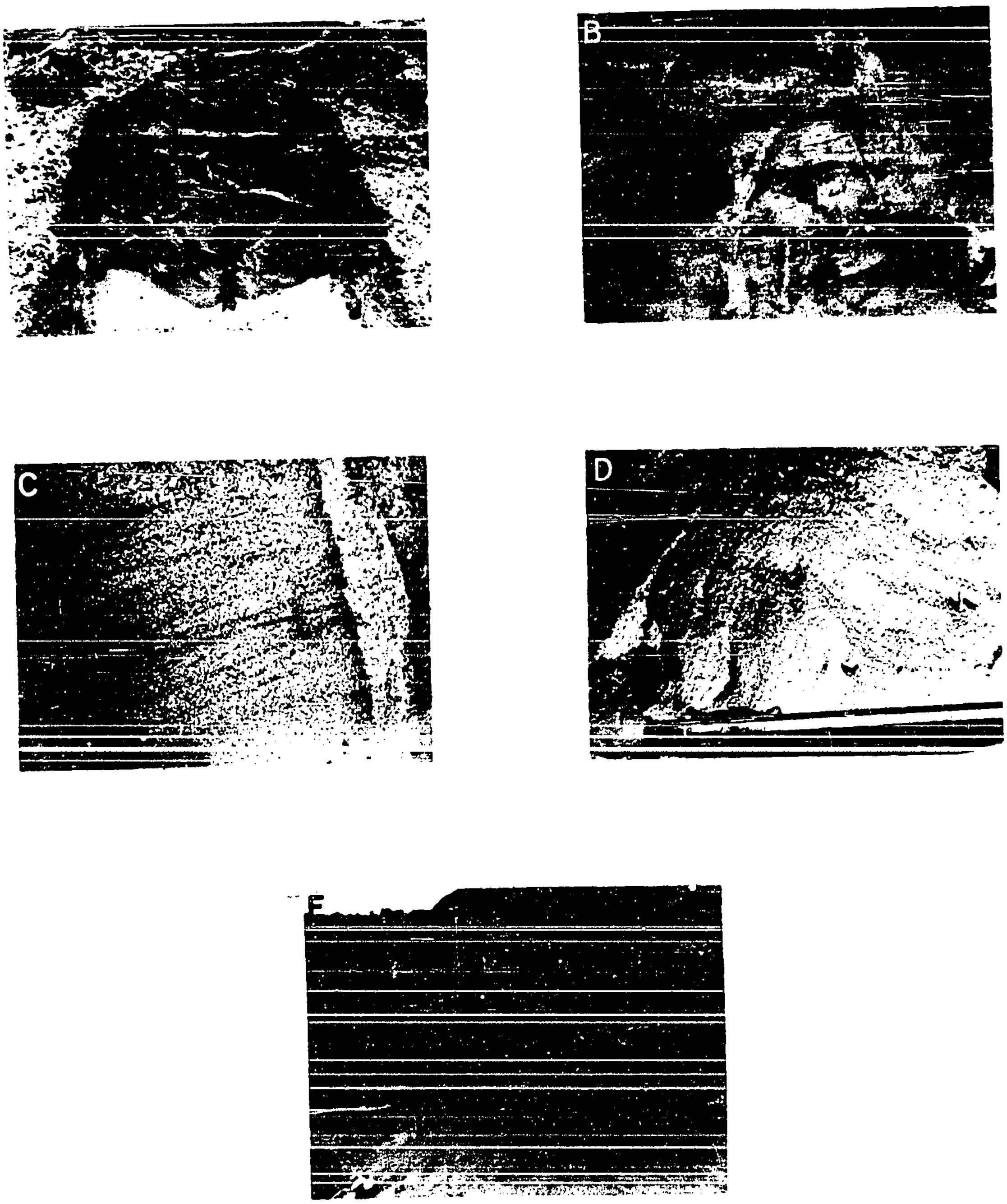
The lithologies and primary structures of fluvial deposits accumulating on marine delta plains are well documented (Welder, 1959; Morgan, 1967; Allen, 1965; Coleman and Gagliano, 1965; Morgan et al., 1968; Berryhill et al., 1969; Fisher, 1969; Frazier and Osanik, 1961; Bernard et al., 1970; Donaldson et al., 1970; Kanes, 1970 and many

Fig. 27. Photographs of lenticular fine-grained sandstone and lenticular-bedded siltstone facies

a-c. Distributary channel sandstones showing small-scale cross-bedding, pebble lenses and rootcasts.

d. Disturbed bedding occurs frequently in these sandstones

e. Lenticular-bedding siltstones that are bioturbated are characteristic of this facies



others). Although the characteristics of fluvial sediments are not as well documented for lacustrine deltas (Arnal, 1961; Wulf, 1963; Axelsson, 1967; Butzer, 1970; Kamp, 1973 and Pezzetta, 1973) the major difference seems to be only one of scale. The lithologies, sedimentary structures and the slightly abraded condition of most of the vertebrate fauna of this facies suggest deposition in a low energy fluvial-delta plain environment. The sandstones possess primary structures and sequences of primary structures similar to those found in recent distributary channel point bar and levee deposits while the siltstones are analogous to interdistributary floodbasin sediments (Allen, 1965; Coleman and Gagliano, 1965; Frazier and Osanik, 1961; Donaldson et al., 1970 and Kanes, 1970). The sequence of primary structures that was noted in the distorted bedded, silty sandstones has been described from point bar and levee deposits on the Mississippi River delta plain (Coleman and Gagliano, 1965). This feature has also been observed by the writer in distributary channel sands in the Lake Rudolf area. An increase in shear stress acting on the bottom causing deformation of laminations occurs during flooding. The relatively thin sequence of cross-bed sets capped by a silt drape would also indicate periodic flooding with intervals of slack water. The origin of cross-stratification has been discussed by Allen (1963). He has demonstrated that the various types are related to the amount of suspended sediment load and flow velocities. The predominance of Kappa cross-stratification over Nu cross-stratification suggests that erosion was not prevalent and only occurred during periodic flooding (Allen, 1963). The occasional lenses of Etheria indicate that at least some of the distributaries were perennial streams.

Lenticular Conglomerate, Sandstone and Mudstone Facies

This facies occurs along the eastern margin of the East Rudolf embayment. It occurs primarily in the lower portion of the Kubi Algi Formation and in the upper portion of the Koobi Fora Formation along the Karari escarpment and south toward Shin and along the eastern portion of the Koobi Fora ridge. The facies also occurs in isolated outcrops between the Kokoi horst complex and the Koobi Fora ridge and along the basin margin east of Ileret.

The lenticular conglomerate, sandstone and mudstone facies is the most heterogeneous of the four facies described. It consists of a complex variety of microfacies which grade laterally and vertically into one another, wedge in, thicken and pinch out. Along the Karari escarpment the facies maintains a nearly constant thickness of about 40 meters but thins noticeably to 20 meters south and west along the Koobi Fora ridge. West along the Koobi Fora ridge this facies grades laterally into the lenticular fine-grained sandstone and lenticular-bedded siltstones facies but south of the ridge the facies rests unconformably on the laminated siltstone facies.

Lenses of grayish orange (10YR7/4), granule to cobble conglomerate and fine to coarse-grained sandstone (arkose or feldspathic litharenite) occurring in sinuous depressions eroded into older deposits and associated finer-grained, very pale orange (10YR8/2) to grayish orange

(10YR7/4) siltstones, claystones, mudstones and light gray (N-7) tuffs comprise this facies. The conglomerates are most abundant to the east along the margin of the basin and in the axial portion of channels or in the basal portion of fining upward lenses. They diminish in grain size toward the center of the basin as well as vertically within individual channels. The sandstones display a variety of primary structures but two basic sequences predominate. The first occurs in sandstone lenses several meters in thickness with a basal surface eroded into older deposits. This begins with high angle (up to 25°) large-scale trough cross-bedded (Pi) conglomerate or coarse-grained sandstone with cosets that are usually uniform in thickness and up to 70 centimeters thick giving way vertically to small-scale trough cross-bedded (Nu) with 3 to 4 centimeter thick cosets and to ripple-laminated (Kappa) fine to medium-grained sandstone. This is usually overlain by a very argillaceous sandstone or sandy siltstone that is parallel laminated and contains numerous calcareous root casts and concretions. This cycle which may be up to 8 meters thick is frequently followed by several more. The coarse-grained basal sandstones contain clay galls and armored mud balls, abraded vertebrate fossils and load casts. The ripple-laminated fine-grained argillaceous sandstones contain numerous calcareous root casts and an occasional small lenticular conglomerate channel which may be trough cross-bedded (Nu). Lenses or banks of the freshwater oyster Etheria occasionally occur within these units. The second sequence is not so consistent and is present in lenses which are usually no more than 2 meters in thickness. The basal surface is usually erosional and is succeeded by either weakly imbricated conglomerates or by Pi type cross-bedded medium to coarse-grained sandstones with cosets that are highly variable in thickness but are no more than 15 centimeters thick, the trough sets diminish in size (to about 3 centimeters in thickness) upward and are usually planed by erosion or are occasionally draped with a thin veneer of argillaceous silt. Both basal sequences are overlain by large-scale planar (Gamma) cross-bedded fine to medium-grained sandstone which contains alternating coarse-fine foresets vertically. These cross-beds usually dip at about 22° and the cosets although high variable range up to 30 centimeters in thickness. This sequence may be capped with thin parallel laminated siltstones or sandstones but is usually truncated and followed by another similar sequence. Calcareous root casts and concretions are numerous in these sandstones but vertebrate fossils and artifacts are only locally abundant. *Etheria* is absent in this second type of primary structure sequence.

Laterally the sandstones grade and interfinger with coarse-grained siltstones, mudstones and highly lenticular tuffs. They are parallel laminated and lenticular-bedded to massive. Convolute bedding is relatively rare in this sequence but does occur locally in the siltstones and tuffs. These fine-grained sediments contain numerous sand and clay lenses. Calcareous root casts with accompanying concretions and/or caliche, mud cracks and incipient fossil soil horizons are locally contained in these sediments (Fig. 28).

This facies is analogous with recent fluvial deposits described by Frazier and Osanik (1961), Allen (1965), Royse (1970), Williams (1971), Smith (1971) and many others. Both primary structures and sequences

Fig. 28. Photographs of lenticular conglomerate, sandstone and mudstone facies

a. Basalt conglomerate showing cut and fill structure and large-scale cross-bedding

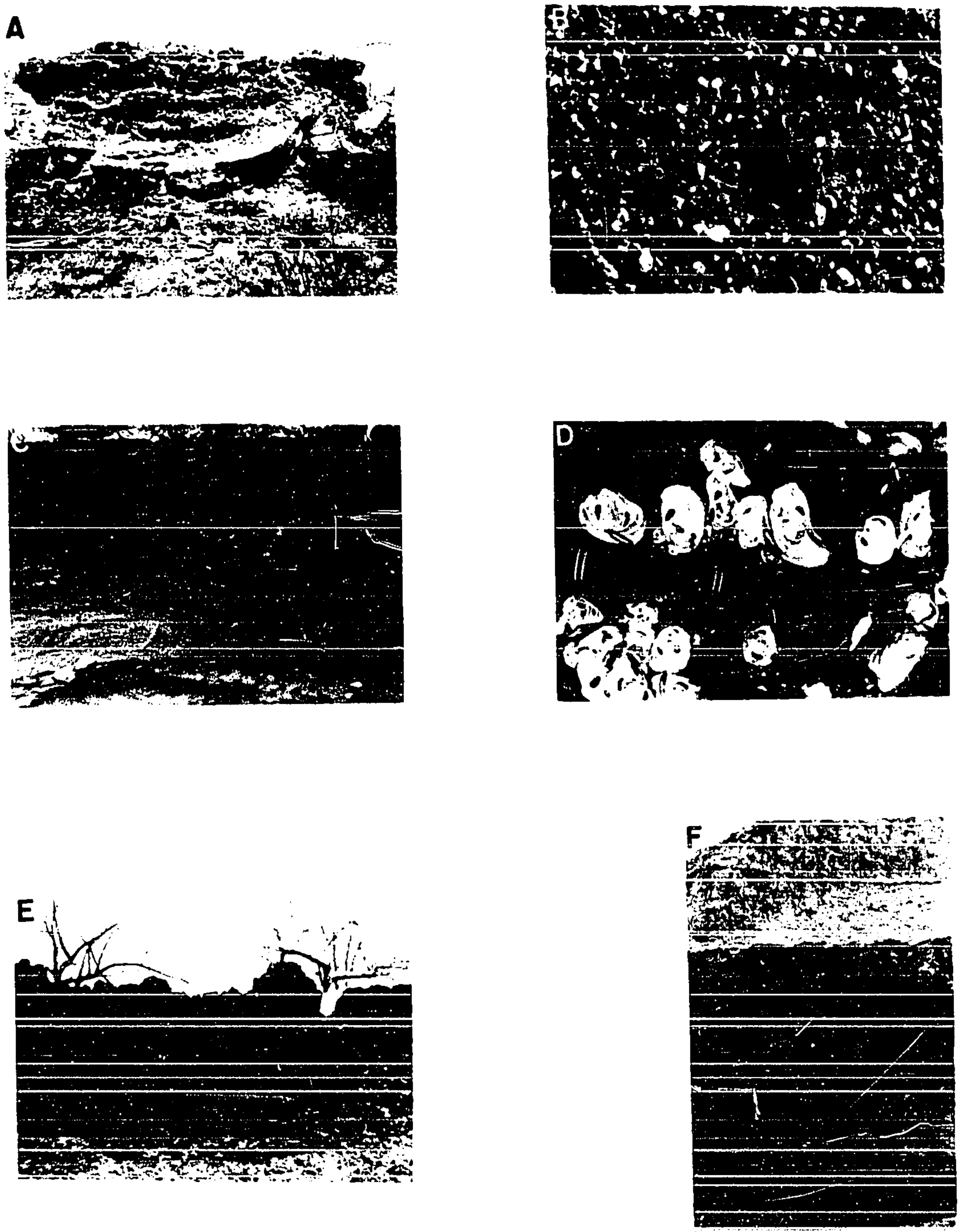
b. Conglomerate composed of granite, gneiss, ignibrite and basal pebbles

c. Typical trough cross-bedded sandstone

d. _Etheria_ occur in sandstones in this facies

e. Levees are rare and show little relief

f. Floodbasin deposits are common and are bioturbated


A
D
E
F

of primary structures have been shown to be related to specific conditions and environments of deposition within the fluvial regime (Allen, 1963; 1965; Williams, 1966; 1968; 1971; Harms and Fahnstock, 1965; Jopling and Walker, 1968; Coleman, 1969; Royse, 1970; Smith, 1971 and many others). Pi cross-stratification, which exists in both sequences, is formed by the migration of large-scale lunate ripple trains with curved crests (Allen, 1963 and Williams, 1968) but the sediment supplied from suspension during the interval of time required for a ripple to advance its own length must be substantially less than the volume of the ripple body (Allen, 1963). As each ripple advances, it erodes a trough on its concave side which is subsequently filled by ripples in the advancing train (Hamblin, 1961; Allen, 1963 and Williams, 1968). This suggests that the erosional energies of these streams was quite high during the formation of the Pi cross-beds. Pi cross-beds, then, are generated by high-stage flow in both meandering and braided stream complexes (Allen, 1963; Harms and Fahnstock, 1965 and Williams, 1971). In the first sequence of primary structures the Pi cross-beds grade vertically to Nu type cross-stratification. Nu cross-beds are formed by migration of trains of linguoid asymmetrical ripples with slightly less energy but under similar conditions that formed Pi cross-beds. Kappa type ripple cross-stratification follows the Nu cross-beds. They form when sediment supply from suspension during the time required for the ripple to advance its own length is greater than the volume of the ripple body (Allen, 1963). Under these conditions, the ripples are not eroded, but are added to both the lee and stoss sides. Formation of this type of cross-stratification would require periodic large suspended sediment loads and low uniform flow velocities (Allen, 1963). The uniformity of the cross-bedded cosets also suggest uniformity of flow. Since this entire sequence is invariably capped by parallel laminated argillaceous to silty sandstones which are attributed to products of vertical accretion, it probably represents point bar deposition in either a meandering or braided stream complex. The presence of Etheria in lenses or banks indicates that these streams were perennial.

The planar cross-stratification of the second sequence has been observed in cross-stratified units that have been constructed in shallow water by the building of solitary banks with straight or curved leading edges above slip-off faces (McKee, 1957; Leopold and Wolman, 1957 and Hoyt, 1969). The solitary banks have been observed to form in modern streams of the braided type (Allen, 1963). Williams (1971) attributed the formation of planar (tabular) cross-stratified sets to deposition by transverse and linguoid bars generated by waning and low-stage flow in ephemeral braided streams. Smith (1971) in studies on the Platte River, Nebraska, confirmed that planar type cross-beds are formed under low-stage conditions in transverse bars. He also noted that the foresets of transverse bars are frequently composed of alternating coarse and fine laminations which he attributed to avalanching of sediment previously sorted by small bed forms on the bar surface upstream from the slip face. The sequence from trough to planar cross-beds which are truncated by other cycles has been noted by Williams (1971) in deposits of ephemeral streams in Australia. This together with the high variability of the thickness of the cosets and the scarcity of fine-grained sediments indicate that the sequence was deposited as channel bars under highly variable flow conditions. The lack of Etheria would suggest that these streams were likely ephemeral.

The siltstones, mudstones and tuffs were deposited in a variety of minor flood plain environments ranging from those immediately proximal to the channel to the distal flood basin. Tuffs were deposited and preserved as usually lenticular beds in the ephemeral streams and in backwater and cutoff channel segments, swales and flood basin depressions associated with ephemeral as well as permanent streams.

TECTONIC AND PALEOGEOGRAPHIC HISTORY

Paleogeographic reconstruction of the northeastern part of the Lake Rudolf basin based on the four major facies, their areal distribution and the correlation of the tuffs can be made in a general sense. Assuming that the correlation of the tuff units is correct and that individual tuffs were deposited everywhere at the same time the tuffs can be used for time-stratigraphic control. By delineating the facies between successive tuffs a general but reasonable picture of the major depositional environments, their areal distribution, the approximate position of the shore line and the approximate location of major streams for a given interval of time can be reconstructed. The Paleogeographic development is summarized by the following maps, schematic reconstructions and interpretative cross-sections (Figs. 29 through 38).

The development of the Lake Rudolf basin has been a continuous process since the Miocene. Middle Pliocene arching of major domes to the east and faulting to the west in the Turkana depression resulted in a shallow asymmetrical westward tilted north - south trough or half-graben in which the Upper Cenozoic sedimentary wedge accumulated (Fig. 35). The uplift was accompanied by igneous intrusion and the associated eruption of obsidian and ignimbrite followed by Late Pliocene basaltic volcanism forming the major volcanic features along the margin of the basin prior to deposition of the basal units of the Kubi Algi Formation. Faults along the sediment-volcanic contact at Kubi Algi and Sibilot indicating post-depositional uplift, reflect the continuing development of the basin and suggest a much more subdued relief during the Plio-Pleistocene than

Fig. 29. An interpretative cross-section of the Upper Cenozoic sediments in the Koobi Fora Area

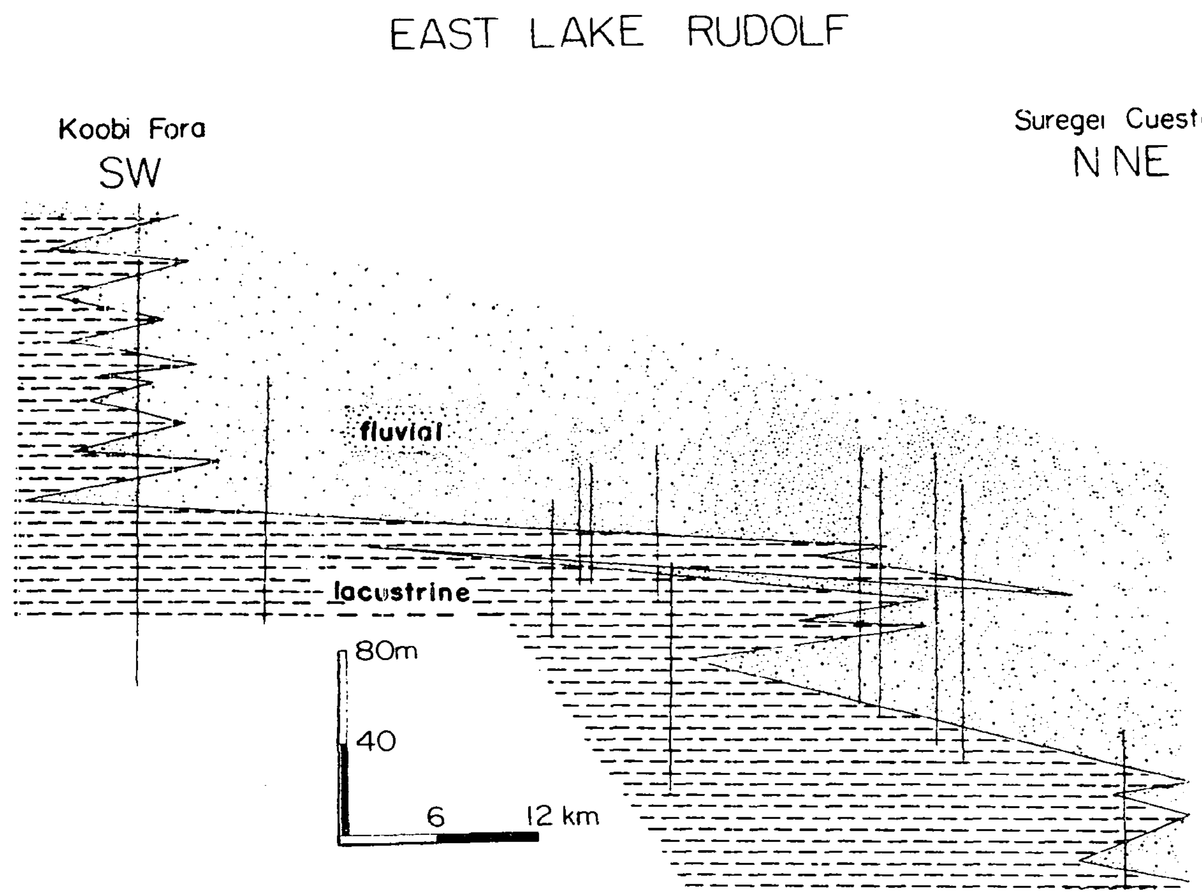

EAST LAKE RUDOLF
Koobi Fora
SW
Suregei Cuesta
N NE
fluvial
lacustrine
80m
40
6
12 km

Fig. 30. An interpretative cross-section of the Upper Cenozoic sediments in the Ileret Area.

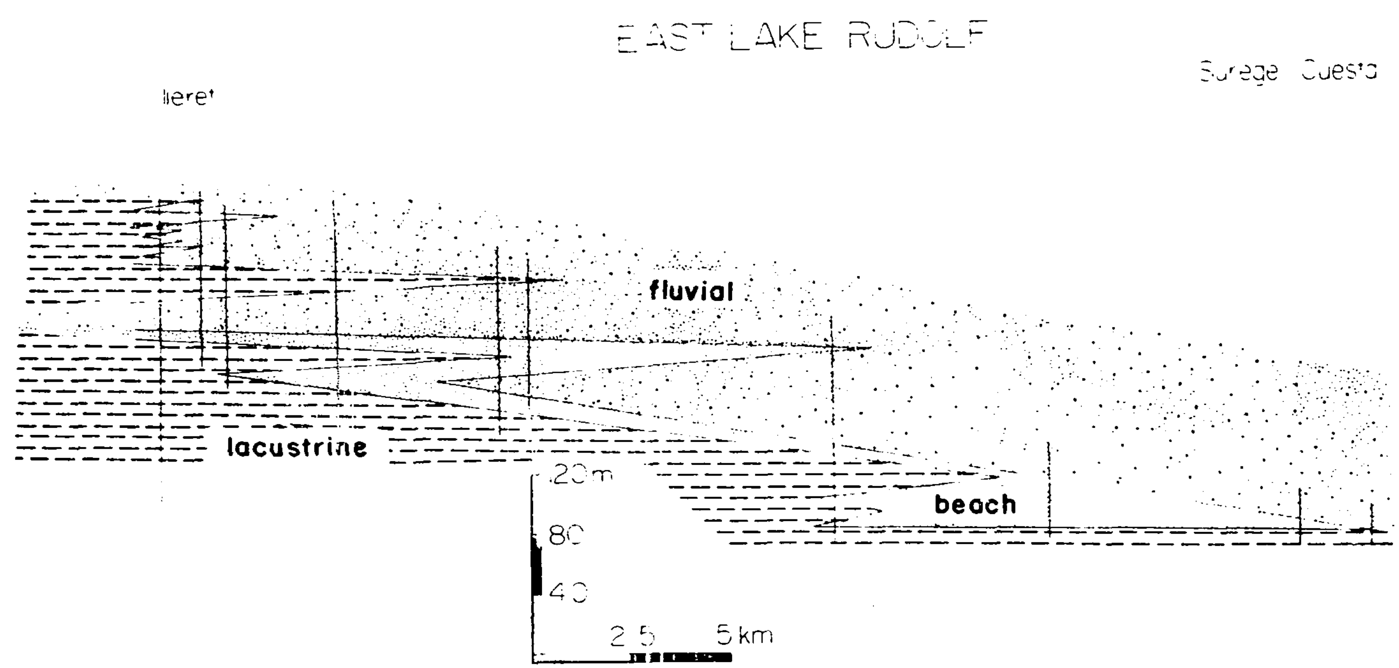

EAST LAKE RUDOLF
Surege Cuesta
fluvial
lacustrine
beach
20m
80
40
2.5
5 km

Fig. 31. Map showing approximate location of the shore line at the time of Suregei Tuff Complex deposition

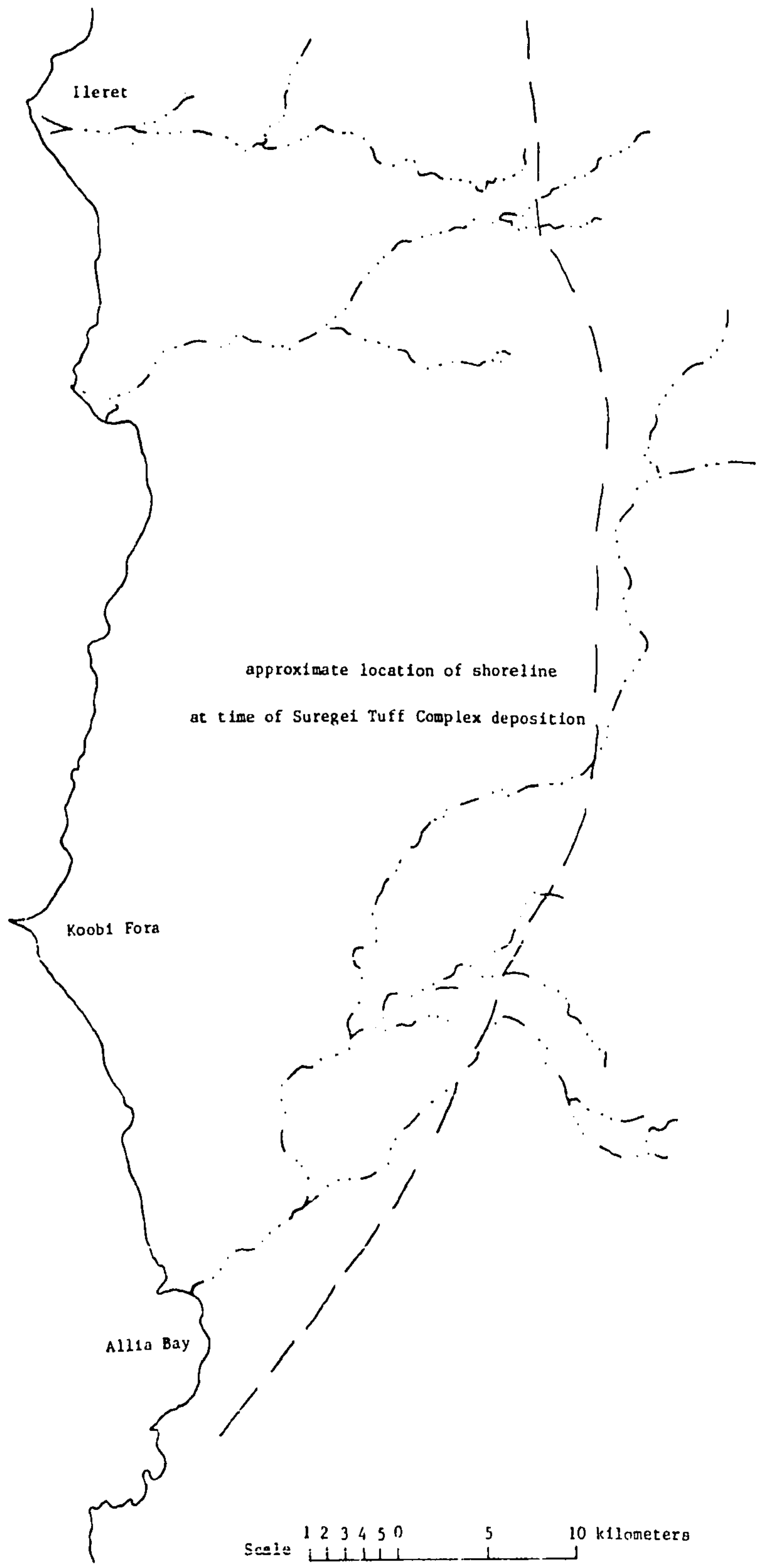

Ileret
approximate location of shoreline
at time of Suregei Tuff Complex deposition
Koobi Fora
Allia Bay
Scale 1 2 3 4 5 0 5 10 kilometers

Fig. 32. Map showing approximate location of the shore line at the time of the Tulu Bor Tuff deposition

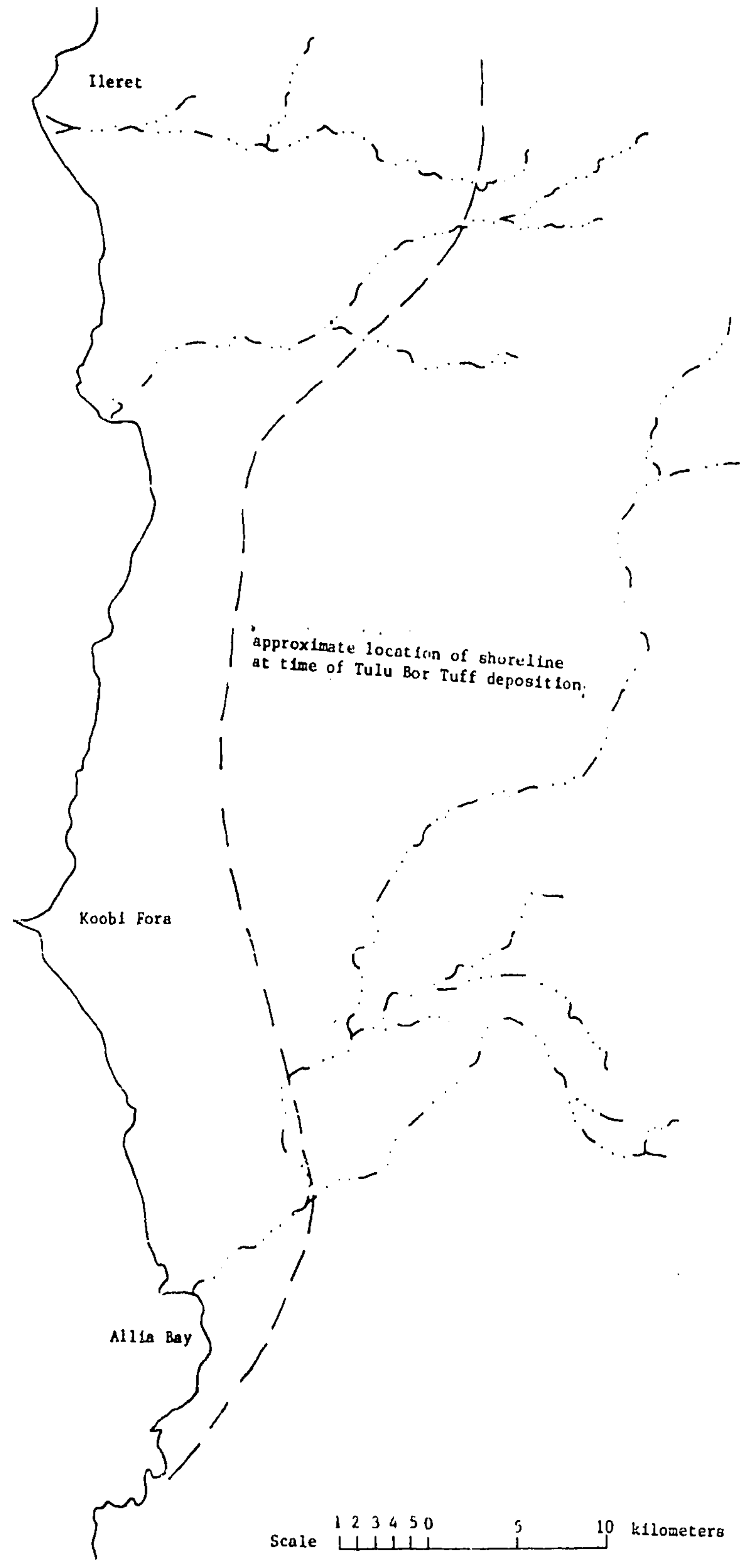

Ileret
approximate location of shoreline
at time of Tulu Bor Tuff deposition
Koobi Fora
Allia Bay
Scale
1 2 3 4 5 0
5
10
kilometers

Fig. 33. Map showing approximate location of the shore line just after the Tulu Bor Tuff

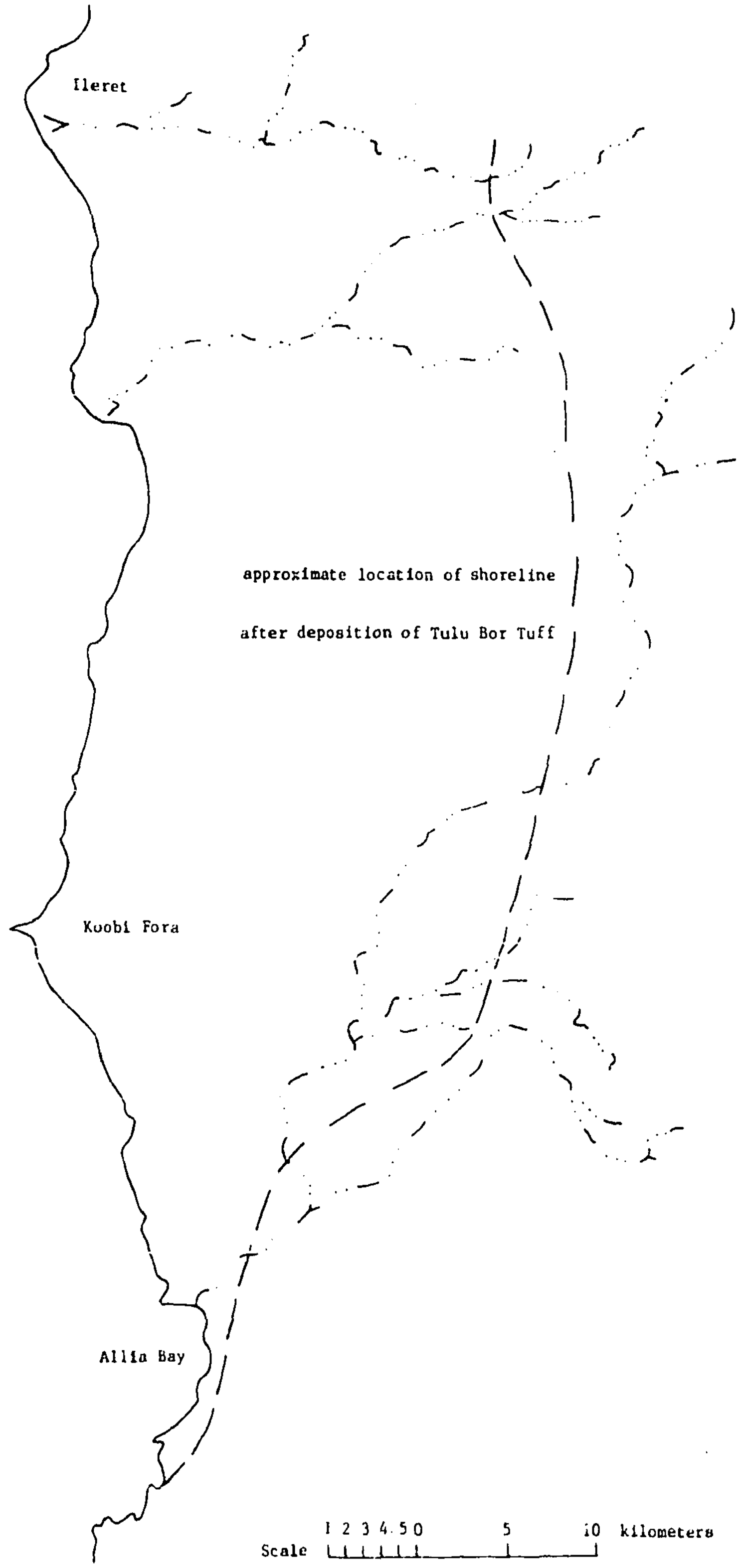

Ileret
approximate location of shoreline
after deposition of Tulu Bor Tuff
Koobi Fora
Allia Bay
Scale
1 2 3 4 5 0
5
10 kilometers

Fig. 34. Map showing approximate location of the shore line at the time of KBS Tuff deposition

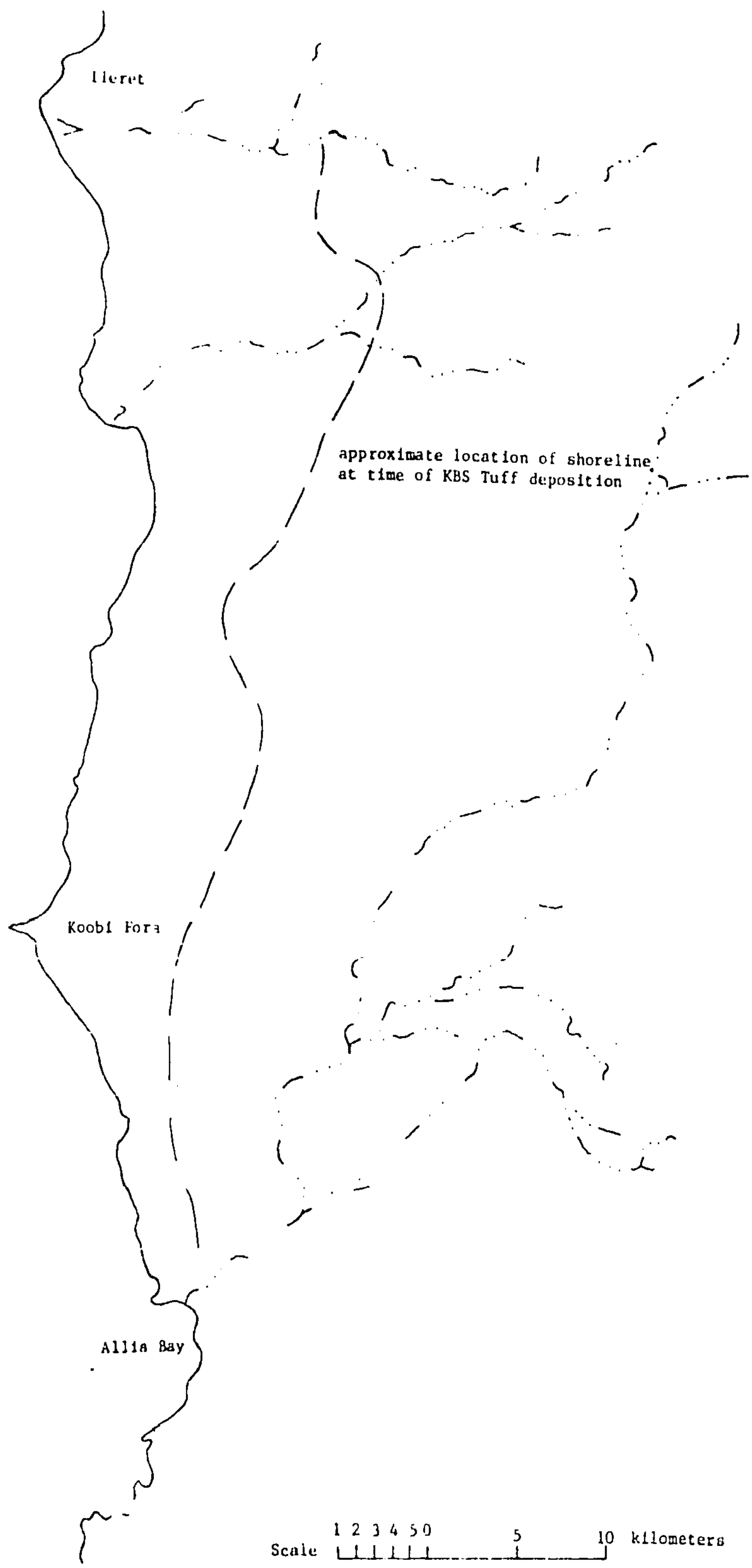
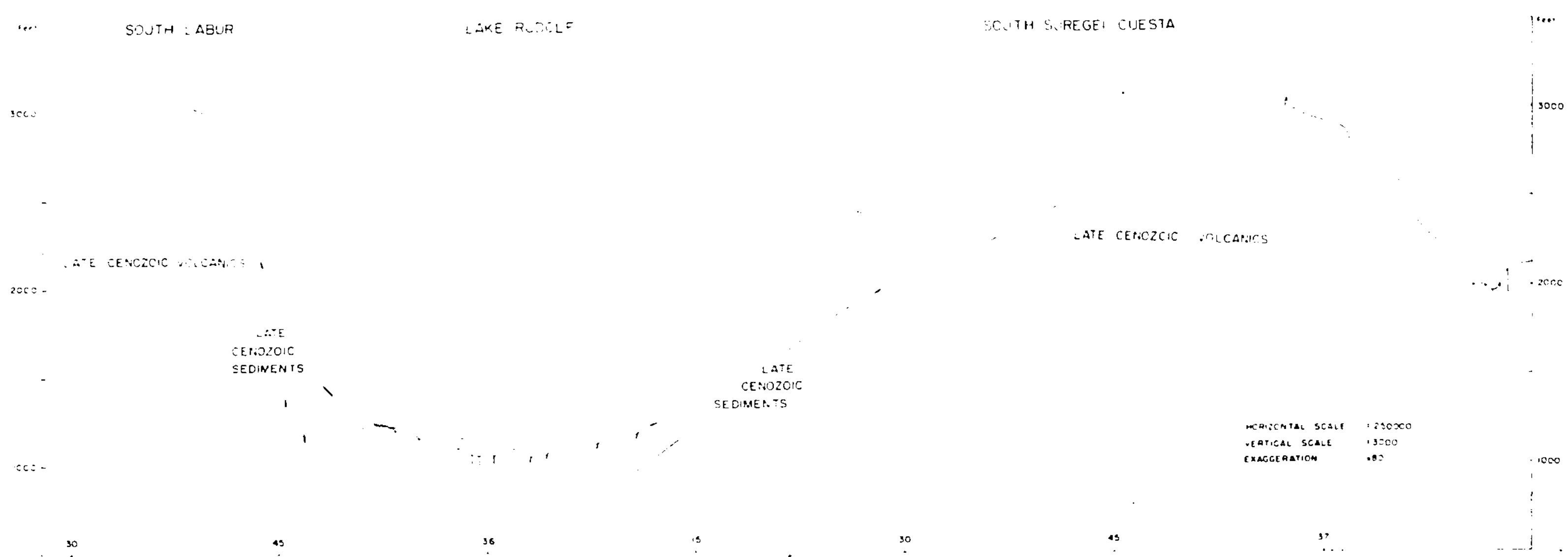

Ileret
approximate location of shoreline
at time of KBS Tuff deposition
Koobi Fora
Allia Bay
1 2 3 4 5 0
5
10 kilometers
Scale

Fig. 35. Schematic cross-section of Northern Kenya Rift System

SCHEMATIC CROSS-SECTION OF NORTHERN KENYA RIFT SYSTEM



in the present. Volcanism continued along the margin of the basin well into the Late Pleistocene as documented by the numerous tuff horizons which occur throughout the Upper Cenozoic sedimentary sequence.

The northeastern part of the Lake Rudolf basin was occupied by a large embayment of the lake during much of the Late Pliocene and Pleistocene. This developed first during the Late Pliocene (about 4.0 myBP) in the Allia Bay area then extended northward shortly thereafter. At the time of the deposition of the Suregei Tuff Complex the lake was at its greatest extent along the Suregei cuesta east of Koobi Fora and Ileret, but had withdrawn to about the position of the present shore line in the Allia Bay area. An interpretation of the depositional environments of the Suregei Tuff Complex indicates the approximate position of the shore line as shown in Fig. 31. The facies occurring below the Suregei Tuff Complex indicate that ephemeral braided streams drained the Suregei cuesta and the local volcanic uplands to the southeast. They formed small alluvial fans composed of boulders and cobbles along the edge of the basin in the Ileret and Koobi Fora areas and small deltas in the Allia Bay area (Figs. 36 and 37). Alluvial fans formed locally along the margin of the lake becoming interbedded with fine-grained lacustrine muds. Beach ridge and barrier beach complexes developed between the alluvial fans. Beach ridges and small back beach lagoons containing thin algal mats also developed in the down current direction from the small deltas in the Allia Bay area.

The depositional environments of the Tulu Bor Tuff and the facies between the Suregei Tuff Complex and the Tulu Bor Tuff indicate a

Fig. 36. Schematic representation of Kubi Algi paleogeography in the Ileret Area.

Alluvial fans formed locally along the margin of the lake becoming interbedded with fine-grained lacustrine muds. Beach ridge complexes developed between the alluvial fans

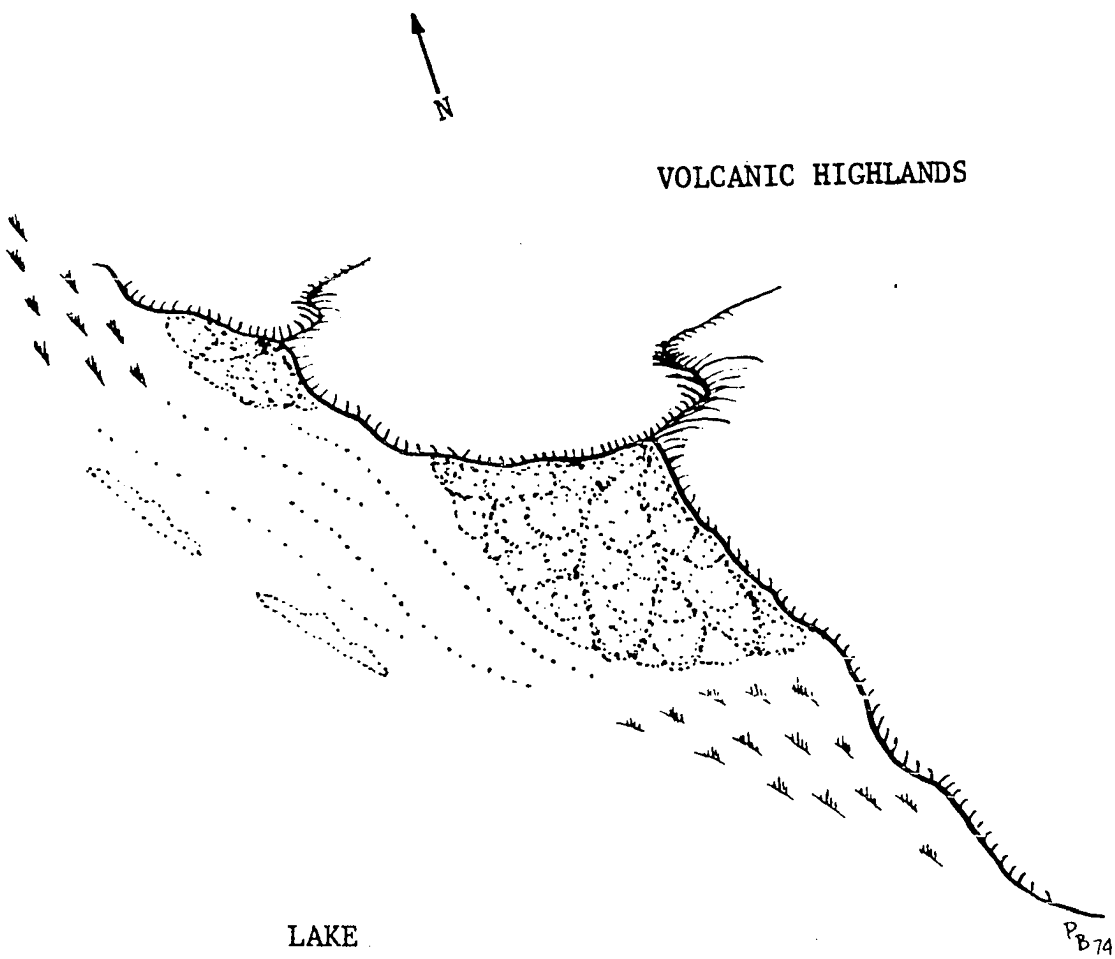
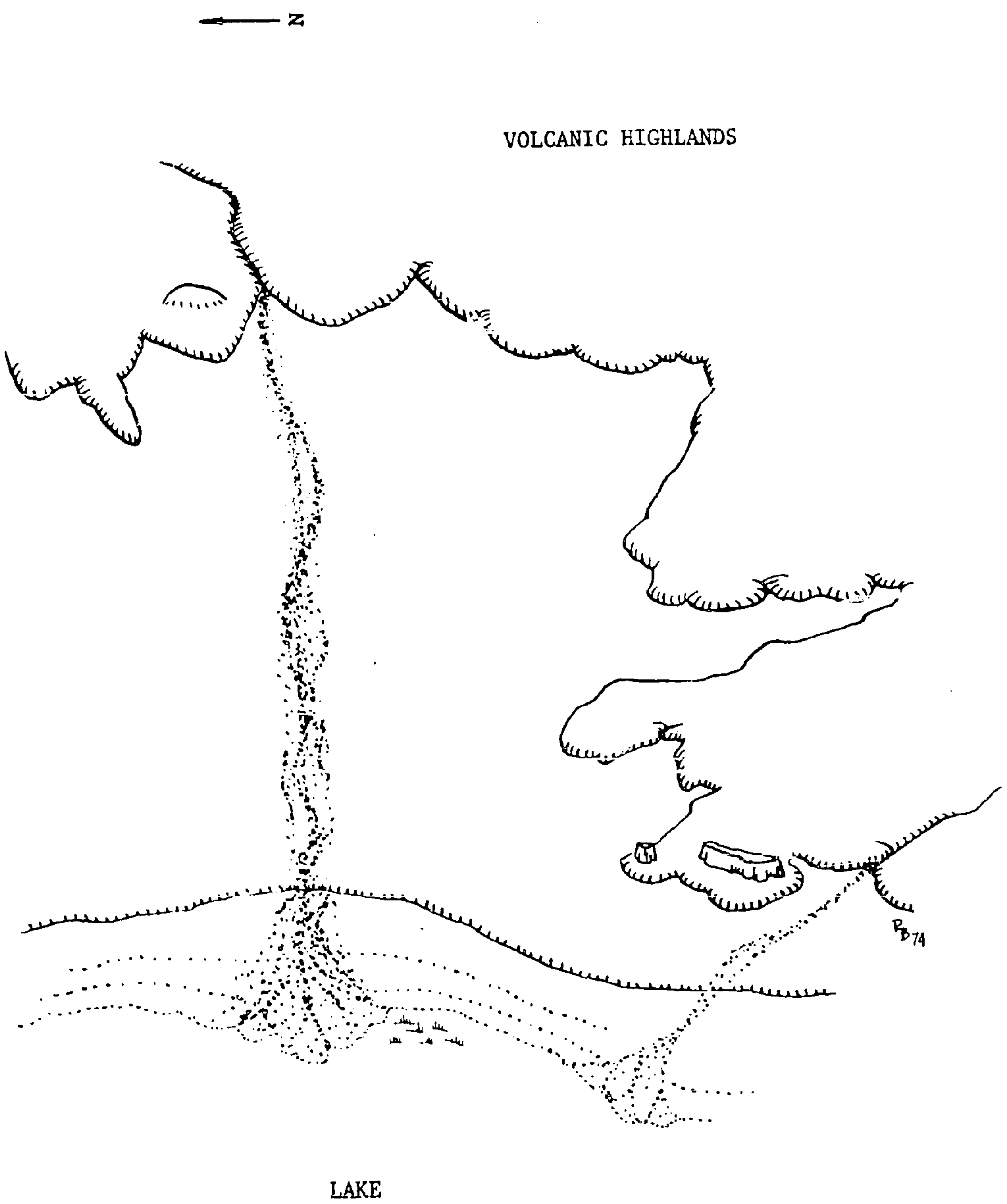

N
VOLCANIC HIGHLANDS
LAKE
PB 74

Fig. 37. Schematic representation of Kubi Algi paleogeography in the Allia Bay Area.

Small, ephemeral braided streams draining the volcanic highlands formed small deltas with intervening beach ridges and back beach lagoons

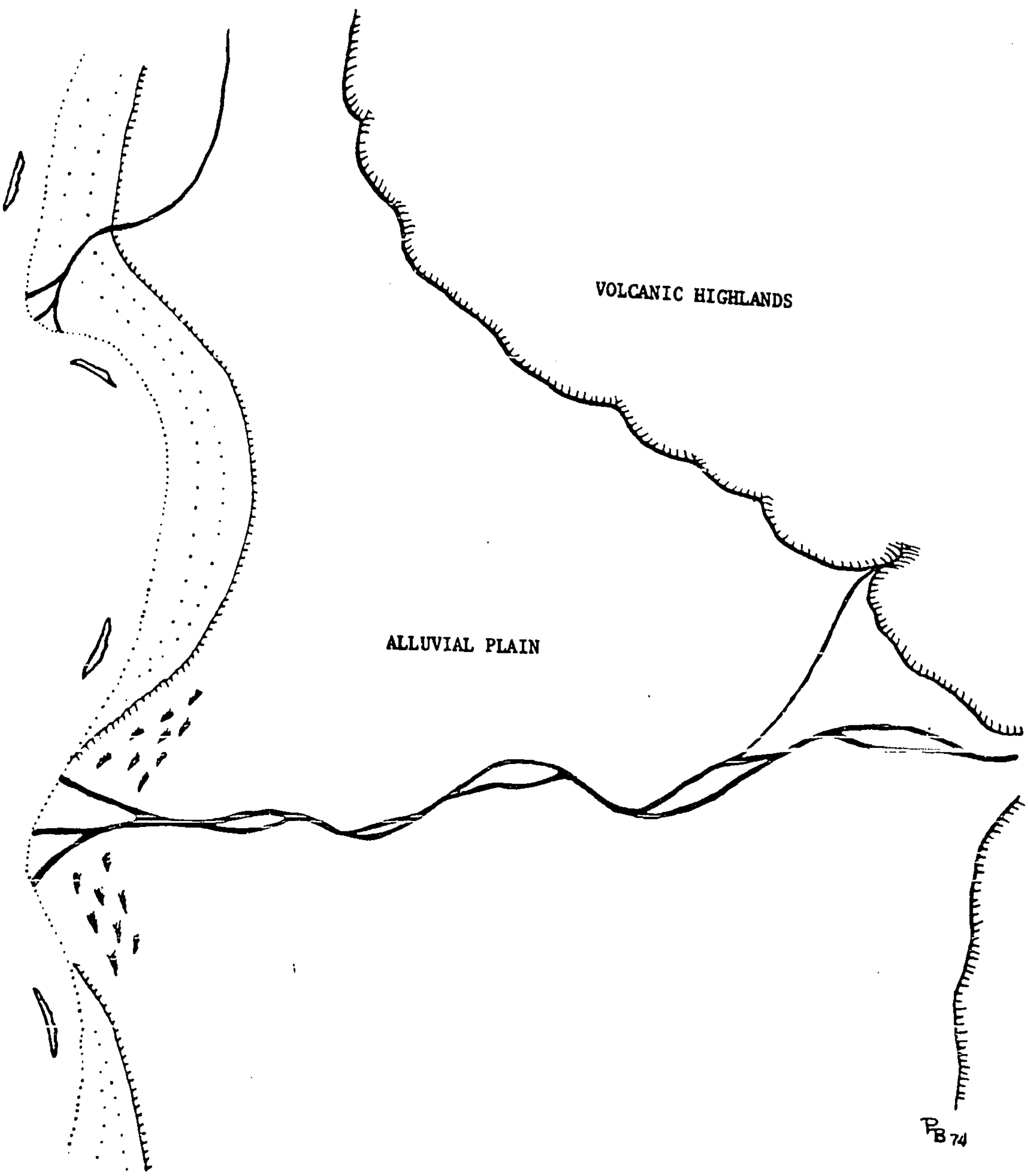

N
VOLCANIC HIGHLANDS
PB 74
LAKE

general westward regression of the lake in the Koobi Fora area (Fig. 29). Primary structures of the lenticular sandstone-lenticular-bedded siltstone facies and the mineralogy of the coarse-grained sediments indicates delta formation by a perennial stream heading to the east. Barrier beach and shelf lacustrine environments were predominate along the basin margin in the Ileret and Allia Bay areas while distal prodeltaic and shallow-shelf deposits accumulated toward the center of the basin.

The widespread laminated siltstone facies, interpreted as prodeltaic and shallow-shelf lacustrine deposits, overlying the Tulu Bor Tuff documents major transgression and southward shifting of the deltaic complex shortly after deposition of the Tulu Bor Tuff (Figs. 32 and 33). By the time the KBS Tuff was deposited perennial streams of low sinuosity had developed prograding deltas in the Ileret and Koobi Fora areas (Fig. 38). Thin lenses of littoral lacustrine deposits were intercalated with the point bars and other deltaic plain sediments documenting short lived lacustrine transgressions. Primary structures and the mineralogy of the coarse-grained sediment indicate that the streams headed to the east and northeast probably deriving a large portion of their sediment from Precambrian plutonic igneous and metamorphic rocks exposed on the flanks of the Stephanie Arch. The fluvial sediments of one of the stream complexes have been traced along the present drainage of the Laga Bura Hasuma and into the Stephanie basin. This further suggests that the streams headed on the flanks of the Stephanie Arch and flowed through "gaps" in the volcanics into the Rudolf basin.

Fig. 38. Schematic representation of the paleogeography at the time of KBS Tuff deposition.

The development of two prograding deltas in the Ileret and Koobi Fora areas is shown


VOLCANIC HIGHLANDS
ALLUVIAL PLAIN
PB 74

Progradation of the deltas continued after the deposition of the KBS Tuff and as the presence of the lenticular sandstone-lenticular siltstone facies along the present shore line at Ileret indicates major regression occurred at this time. Alternating arenaceous bioclastic carbonate and lenticular sandstone-lenticular bedded siltstone facies above the major regression documents a series of minor transgressions and regressions with a major regression occurring at the end of the deposition of the Koobi Fora Formation. Fluvial conditions persisted in the Allia Bay and Koobi Fora areas until the advent of a major Holocene lacustrine transgression which resulted in the deposition of the Galana Boi lacustrine (Vondra et al., 1971). In the Ileret area, however, the Late Pleistocene Guomde Formation represents a limited lacustrine transgression and regression prior to the Holocene transgression and Galana Boi deposition. Although the stratigraphy and lateral relationships of the Holocene sequence is not known in detail an approximation of the maximum extent of the lake can be made based on the areal distribution of the Galana Boi beds.

The impetus for delta growth and major regression was probably the elevation of the source area and downwarping of the lake basin as a result of periodic tectonic activity along the rift. Although climatic changes certainly affected the position of the shore line, numerous tectonic features in the Lake Rudolf basin indicate that tectonic processes have been active periodically during deposition and were likely the dominate processes. Major faulting on the west side of the lake occurred in the early Pliocene and again in the Pleistocene (Walsh and

Dodson, 1969). This follows very closely the activity reported by Dodson (1963) for the southern end of the lake. The major faults of the Kokoi horst complex, the occurrence of Galana Boi sediments at elevations up to 120 meters above the present shore line in the eastern part of the Lake Rudolf basin and Galana Boi equivalents on the west side of the lake dipping as much as 45° to the east (personal communication, J. Walsh, 1973) further indicate that tectonic activity continues to be a dominant process in the Recent.

SUMMARY AND CONCLUSIONS

(1) The Upper Cenozoic of the East Rudolf embayment consists of 325 meters of fluvial, deltaic, transitional lacustrine and lacustrine sediments deposited disconformably on a basement of Late Miocene and Pliocene volcanics and interbedded sediments and paleosols in a north-south trending asymmetrical trough or half-graben bounded on the west by a major fracture system and on the east by a monoclinal flexture.

(2) Three formal lithostratigraphic units and one informal unit have been established. The basal unit, the Kubi Algi Formation, consists of a 90 meter complex of interbedded and interfingering lenticular conglomerates, sandstones, siltstones and occasional laminated tuffs. The Koobi Fora Formation, which has been subdivided into a Lower and an Upper Member in the Koobi Fora area and a Lower and Ileret Member in the Ileret area, conformably overlies the Kubi Algi Formation. It also consists of a 200 meter complex of interbedded conglomerates, sandstones, carbonates, siltstones and tuffs. The Guomde Formation lies unconformably on the Koobi Fora Formation in the Ileret area to which it is restricted. It consists of 35 meters of laminated siltstones and molluscan carbonates with intertongue of trough cross-bedded sandstones and conglomerates. The sequence is capped by a tuff. The Plio-Pleistocene sediments are unconformably overlain by the Holocene Galana Boi beds. The distribution of these lithostratigraphic units have been mapped and geologic maps of 1:50,000 scale have been presented.

(3) The conglomerates and sandstones vary in composition from arkosic to litharenitic. Their composition reflects the composition of the source area, distance from the margin of the basin and the degree of weathering and amount of recycling to which the sediments were subjected. Siltstones, mudstones and claystones are mainly quartz with montmorillonite dominant among the clay minerals. Carbonates are, for the most part, packed molluscan biosparudites although there are some very sandy to argillaceous carbonates which are interpreted as caliche. The tuffs consists of very fine to coarse-silt sized glass shards. They are locally argillaceous, sandy and may contain pumice cobbles up to 30 centimeters in diameter.

(4) Four major lithofacies have been recognized in the Late Cenozoic sediments in the northeastern part of the Lake Rudolf Basin. These are (1) the laminated siltstone facies; (2) the arenaceous bioclastic carbonate facies; (3) the lenticular fine-grained sandstone and lenticular-bedded siltstone facies; and (4) the intertongued lenticular conglomerate, sandstone and mudstone facies. These are interpreted are representing for major depositional environments (1) prodelta and shallow-shelf lacustrine; (2) littoral lacustrine--beach and barrier beach and associated barrier and supralittoral lagoons; (3) delta plain; and (4) fluvial channel and flood plain.

(5) The variation in the petrology of the sandstones in the Ileret, Koobi Fora and Allia Bay areas, the distribution of the facies and

the interpretation of the primary structures indicates that the sediments in the Ileret and Koobi Fora areas were deposited as two fluvial and prograding deltaic complexes formed by major perennial streams. Sand-bed ephemeral streams draining the local volcanic highlands were responsible for most of the Upper Cenozoic sediments deposited in the Allia Bay area.

(6) The mineralogy of the coarse sediments in the Ileret and Koobi Fora areas suggest that the streams headed to the northeast and east and received sediments from Precambrian plutonic igneous and metamorphic rocks exposed on the flanks of the Stephanie Arch and from volcanics on the Suregei cuesta.

(7) The concordant relationship between the sediments and the underlying volcanics of the Suregei cuesta, the alluvial cones along the basin margin and the occurrence of Late Cenozoic fluvial conglomerates in the Lake Stephanie basin suggest a moderate relief in the Late Pliocene on the basin margin volcanics and gaps in the volcanics through which the streams that drained the flanks of the Stephanie Arch flowed.

(8) Delta growth and the continual regression is attributed primarily to elevation of the source area and downwarping of the lake basin as a result of periodic activity along the rift. Although climatic changes undoubtedly affected the position of the shore line, numerous tectonic features around the Lake Rudolf basin indicate that activity along the rift has continued into the Recent.

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ACKNOWLEDGMENTS

The research for this report was made possible by National Science Foundation Grants GA-25684 and GS-37813 to Dr. Carl F. Vondra and in part by National Geographic Society grants to R. E. Leakey. The work was aided by the assistance and cooperation of the National Museums of Kenya and the Kenyan Government. The writer wishes to extend special thanks to Dr. Carl F. Vondra for his supervision throughout all phases of the study. His assistance both in the field as well as in preparation of this manuscript was invaluable to the successful completion of the project. Grateful acknowledgment is also made to Dr. John Lemish and Dr. Keith M. Hussey of the Department of Earth Science, to Dr. Thomas Fenton and Mr. Gerald Miller of the Soil Science division of the Department of Agronomy and to Dr. Larry D. Wing, Department of Zoology and Entomology at Iowa State University for their valuable suggestions, guidance and assistance during various portions of the study.

Appreciation is extended to the members of the East Rudolf Research Group particularly to G. D. Johnson, T. E. Cerling, H. Acuff, R. Bainbridge, A. K. Behrensmeyer, F. J. Fitch, I. C. Findlater, H. J. Frank, G. LL. Isaac and R. E. Leakey for their assistance and many helpful suggestions in the field. Thanks is due also to D. Burggraf who drafted the final version of the map and to H. White and members of the 1973 Stratigraphy class who aided in the laboratory analyses.

Sincere thanks is due to Penny Bowen, the writer's wife, for assistance in the field during the 1971 season, for the art work on the

paleogeographic reconstructions and for the understanding given during the past few years of study, particularly during those extended periods while the writer was in the field.